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UNIVERSITY OF ALBERTA

HEDGING PORK CUTS

BY

NIS KJÆR

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science.

IN

AGRICULTURAL ECONOMICS

DEPARTMENT OF RURAL ECONOMY

EDMONTON, ALBERTA

FALL 1992

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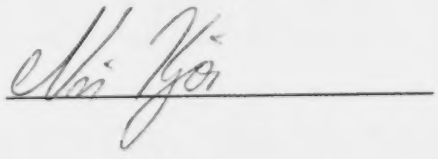

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Dr. G. Barone-Adesi

Dr. M. L. Lerohl

Date: September 4, 1992

Abstract

This thesis investigates how an Alberta meat packer can reduce price risk on pork cuts by hedging them on the Chicago Mercantile Exchange (CME), and derive the cost of risk reduction.

The results from hedging pork bellies and pork loins show that bellies achieve the largest risk reduction when they are hedged on the pork belly futures market, compared to the live hog futures market. The cost of risk reduction of bellies is lowest when bellies are hedged on the pork belly futures market, compared to the live hog futures market.

Loins achieve the largest risk reduction from being hedged on the live hog futures market. The cost of hedging loins are therefore lowest on the live hog futures market.

Bellies achieve more risk reduction from hedging than loins. The cost of hedging bellies is also lower than the costs of hedging loins.

The optimal hedge ratio is derived from comparing the cost of risk reduction to the price of risk in the capital market. The guideline for a price of risk on hedging pork cuts is between 0.20 and 0.40 dollars per standard deviation. The optimal hedge ratio is therefore a hedge ratio which corresponds with this price of risk.

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Chapter I. Introduction

The motivation for this thesis is to analyze how an Alberta meat packer can use the futures markets for live hogs and pork bellies in Chicago to buy risk reduction for forward contracts on pork cuts.

It is assumed that a meat packer with industry-average costs of operation gains a sufficient return for survival on its operation if it continuously trades live hogs and pork cuts on the spot market. This is a reasonable assumption; as long as the industry is stable and a firm in this industry can keep its costs as low as the average for the industry.

Trading pork meat on the spot market might not be the only market strategy that the meat packer can rely on in the future. Several factors could cause the meat packer to try to sell meat on forward markets as well as spot markets. The meat packer could simply be interested in developing new market opportunities to better serve its customers by offering forward contracts on cuts. Increasing competition in the meat packing industry or demands from food retailers could force the meat packer to sell meat on forward contracts.

If the meat packer sells meat on forward contracts, it exposes itself to the risk between the forward price and the spot price at expiry of the forward contract. This thesis then analyzes how a meat packer in Alberta can reduce the risk on forward contracts by taking opposite futures positions. Futures markets for pork do not exist in Canada. The only pork futures markets in North America are the pork belly futures market and the live hog futures market on The Chicago Mercantile Exchange (CME).

The following example illustrates why forward selling of pork meat is a realistic market strategy and some of the practical problems in hedging cuts on CME.

A food retailer decides in the first week of August to offer a discount on bacon and pork chops during the first week of September. The retailer has set its selling prices but it does not know its buying prices. In order to reduce the risk exposure on the buying prices, the retailer asks a meat packer for a four week forward contract on bellies[1] and loins[2] from the first week of August to the first week of September. If the meat packer agrees, the retailer will have eliminated its price risk on the bacon sale, because it now knows the buying and selling price.

But now the meat packer is exposed to the difference between the spot price and the forward price of bellies and loins, because the meat packer does not know what the spot price of bellies and loins in early September will be, it only knows the forward price of bellies and loins in early September. If the meat packer wants to reduce its risk exposure on the difference between the spot prices and the forward prices on bellies and loins, it can do one of two things. 1) It can try to secure the price of the live hogs which are going to be converted into bellies and loins in September by buying the live hogs in the forward or futures markets. 2) The meat packer can try to secure the spot price of bellies and loins only. Securing the price of live hogs not only means securing the price of input to produce bellies and loins but also means securing the price of the input to produce spareribs, hams, butts, picnics, trimmings etc. This may not be desirable if there are no forward sales contracts on these cuts.

The aim of this thesis is to find out how the meat packer can reduce the risk exposure between the spot price and the forward price of bellies and loins. How

---

[1] Bellies become bacon when they are smoked

[2] Loins are cut into pork chops

much risk on the belly and loin price can be reduced? What does it cost? How much should the packer pay? These are all questions that the packer wants answered. As mentioned earlier, the answers will be found on the pork belly and the live hog futures markets in Chicago.

The basic research problems for the thesis are:

1. To determine how much risk[3] a pork meat packer in Alberta can reduce on four week and nine week forward contracts on bellies and loins by hedging them on the live hog futures market and the pork belly futures market on CME.

2. To derive the marginal price[4] of risk reduction on four week and nine week forward contracts on bellies and loins as a function of the relative value of the futures position (the hedge ratio).

I.1 Objectives

This thesis is brought to an end when the following objectives are met:

1. As background, to describe a model for calculating optimal hedge ratios when price is the only source of risk and expanding the model to include brokerage and margin costs.

2. To use historical data from 1985 to 1991 to identify the effect of changing the hedge ratio on the risk reduction and on the marginal price of risk reduction, when cuts are hedged on the live hogs or the pork belly markets on CME.

3. To identify how the length of time over which hedging is done affects both the risk reduction and the marginal price of risk reduction as a function of the hedge ratio.

4. To informally discuss the implications of the empirical findings for a meat packer: What is the marginal price of risk reduction that a meat packer should be willing to pay, and what is the optimal hedge ratio?

---

[3] Price is the only source to risk.

[4] The marginal price of risk reduction is defined as the change in transaction costs divided by the change in risk reduction.

I.2 Study plan

Chapter I presents the introduction, the practical problems that this thesis solves and the objectives of the thesis.

Chapter II describes the theoretical foundation of the optimal hedge ratio and reviews the literature on key issues like efficient futures markets and risk premium in futures markets. The hedge ratio with transaction costs is derived to show that the optimal hedge ratio depends on the hedgers risk aversion when transaction costs are included in the model.

Chapter III discusses the data that are used in the analysis.

Chapter IV shows how the forward prices, profits on forward contracts and profits on futures contracts are simulated. It also indicates how risk and the marginal price of risk reduction is calculated.

Chapter V combines the data from chapter III and the methodology from chapter IV to produce research results. First chapter V presents the risk analysis of the forward markets and the futures markets. Then the main results of this thesis are presented, namely how the risk of four week and nine week forward contracts on bellies and loins can be reduced by hedging on the pork belly and live hog futures markets; and how the price of risk for each cut hedged on both futures markets change as a function of the hedge ratio. The final result of chapter V is a statement of trade-off between risk reduction and cost which is available to a hedger of pork cuts.

Chapter IV discusses how much the meat packer should pay for reducing risk on bellies and loins. In so doing, it is discussing the issue of how high a hedge ratio a forward contractor of pork cuts may wish to maintain.

Chapter II. Theory on optimal hedge ratio and literature

Section II.1 show how Johnson (1960) derived an optimal hedge ratio that is used when the correlation between the cash and futures positions is non-perfect. Then it is shown how the optimal hedge ratio with transaction costs is dependent on the hedger's risk aversion. In section II.2 the literature on optimal hedge ratio is reviewed. Since market efficiency is a key assumption behind the optimal hedge ratio, the literature on risk premiums and efficient pork futures markets are reviewed too.

II.1 Model for the optimal hedge ratio

Johnson (1960) derived the optimal hedge ratio from the mean-variance analysis as it is shown below. Johnson (1960) found that the optimal hedge ratio between a cash position and a futures position is equal to the covariance between the cash position and the futures position divided by the variance of the futures position.

The expected return from a portfolio that contains a cash position and a futures position is equal to (1):

$$(1) \quad E(R_p) = X_s E(R_s) + X_f E(R_f)$$

X_s is the amount of the cash position:
X_f is the amount of the futures position: ($X_f = 1 - X_s$)
$E(R_s)$ is the expected return on the cash position, or $E(S_1) - S_0$:
$E(R_f)$ is the expected return on the futures position, or $E(F_1) - F_0$
The variance on this portfolio is equal to (2):

$$(2) \quad V(R_p) = X_s^2\sigma_s^2 + X_f^2\sigma_f^2 + 2X_sX_f\sigma_{sf}$$

σ^2_s is the variance of the cash return (price change):
σ^2_f is the variance of the futures position (price change):
σ_{sf} is the covariance between the cash and futures prices (returns).

The producers quadratic utility is maximized in equation (3):

$$(3) \quad Max\ E(U) = E(R_p) - \lambda * 1/2 V(R_p)$$

Lambda is the risk aversion parameter. The optimal futures position is derived from setting the first order condition (with respect to X_f) of (3) equal to zero and solving for X_f:

$$(4) \quad X_f^* = \frac{E(F_1) - F_0}{\lambda \sigma_f^2} - \frac{X_s \sigma_{sf}}{\sigma_f^2}$$

If the futures markets are efficient ($E(F_1) - F_0 = 0$), then the expected cash price should equal the present futures price and the first term in (4) for the optimal futures position equals zero leaving (5) as the optimal hedge ratio:

$$(5) \quad \underline{\underline{HR^* = \frac{X_f^*}{X_s} = -\frac{\sigma_{sf}}{\sigma_f^2}}}$$

Equation (5) shows that the optimal hedge ratio is a function of the covariance between the futures and the cash prices over the variance of the futures price. As the correlation between the cash prices and the futures prices gets closer to -1 the hedge ratio gets closer to 1.

The optimal hedge ratio above is derived under the assumption that there are no transaction costs. Transaction costs exist, and they might have an impact on the producer's hedging decision. Transaction costs are brokerage and lost interest on the initial margin. When transaction costs are included in the analysis the optimal hedge ratio becomes dependent on the hedger's risk aversion.

One approach to include transaction costs is to deduct them from the futures price. Transaction costs are a fixed dollar amount per contract, they are converted to a dollar value per pound that can be deducted from the dollar per pound quoted futures price to obtain a futures price after transaction costs.

If the expected return on the futures position is $E(R_f) = E(F_1) - F_0$, without transaction costs and the transaction costs per unit is T_c, then the expected return on the futures position with transaction costs is; $E(R_f) = E(F_1) - F_0 - T_c$.

If this new term for the expected return on the futures position is substituted into the utility function (3) and the first derivative with respect to the futures position (X_f) is taken, the result is equation (6):

$$(6) \quad E(F_1) - F_0 - T_c - \lambda X_f \sigma_f^2 - \lambda X_s \sigma_{sf} = 0$$

From (6) the hedge ratio with transaction costs is (7):

$$(7) \quad HR^*_{T_c} = \frac{X_f}{X_s} = \frac{(E(F_1) - F_0)}{(\lambda X_s \sigma_f^2)} - \frac{T_c}{\lambda X_s \sigma_f^2} - \frac{\sigma_{sf}}{\sigma_f^2}$$

If the futures market is efficient, the optimal hedge ratio with transaction costs is (8):

$$(8) \quad HR^*_{T_c} = \frac{X_f}{X_s} = -\frac{T_c}{\lambda X_s \sigma_f^2} - \frac{\sigma_{sf}}{\sigma_f^2}$$

The difference between (8) and the hedge ratio without transaction costs (5) is the first term in (8), which is (9):

$$(9) \quad \frac{-T_c}{\lambda X_s \sigma_f^2}$$

Equation (9) shows that the optimal hedge ratio decreases when transaction costs are introduced. The decrease in hedge ratio depends on the level of the transaction costs, the variance of the futures price and the producer's risk aversion. The transaction costs' effect on the hedge ratio disappears only if the hedger is very risk averse (lambda $=> \infty$).

II.2 Literature on optimal hedge ratio, risk premium and market efficiency

Most of the literature on optimal hedge ratio can be traced back to Johnson (1960). Ward and Fletcher (1971), Heifer (1972 and 1973), Kahl (1983) Peck (1975) all confirm the optimal hedge ratio derived by Johnson, where the origin of the model for the optimal hedge ratio is the mean-variance approach.

Bond and Thompson (1986) analyzed the optimal hedge ratio within the Capital Asset Pricing Model (CAPM) framework. They found that the optimal hedge ratio for commodity is reduced significantly when stock market shares are added to the portfolio of cash and futures positions. Bond and Thompson (1985) showed that the hedger's risk aversion will alter the optimal hedge ratio when transaction costs are included in the analysis of the optimal hedge ratio. Bond et al. (1986) analyzed the implications on the optimal hedge ratio when expectations about the futures market profits change. They found that the optimal hedge ratio is affected when the profit expectations on the futures markets are different from zero.

A key assumption behind Johnson's optimal hedge ratio is the assumption about market equilibrium and thereby the question about wether risk premiums exists in futures markets or not. This last part of this section will review the literature on this assumption.

Keynes (1930) developed the hypothesis that futures markets provide insurance for hedgers. Producers are considered hedgers and since producers most often are long in the physical market Keynes argued that the hedgers would be willing to pay a risk premium to the speculator in order to attract speculators to buy the short position in the futures market. This lead to the theory of normal backwardation. The theory of normal backwardation says that the futures price will decrease as time to maturity decreases, because the risk premium will decrease.

Theory of normal backwardation has caused a lot of discussion in the finance literature. Probably the most well known article against normal backwardation was written by Telser (1958). Telser argued that there is no reason to expect normal backwardation, because the bidding competition among the speculators drives the speculative profits to zero. Telser's own analysis of futures markets for cotton and wheat suggested no evidence of risk premiums in these futures markets.

The literature after Keynes and Telser has concentrated on empirical testing of normal backwardation and on using the CAPM to verify normal backwardation.

Dusak (1973) used the CAPM to test the futures market for wheat, corn and soybeans for risk premiums. The CAPM predicts risk premiums if the relevant beta values exceed zero. Dusak (1973) did not find beta values significantly different from zero. Dusak (1973) argued that the reason Keynes thought that risk premiums existed in futures market could be, that the British economy at the time of Keynes was much more dependent on commodity prices. The commodities' strong influence on the British economy or market portfolio meant that the beta values of the futures were different from zero. But today, the economy is more diversified and the commodities are less important to the whole economy. Hence, the beta values of commodity futures for an investor of today are not significantly different from zero.

Carter et al. (1983) criticized Dusak for using a misspecified model to estimate the beta values of the futures markets. They developed a model, which estimated the beta values on the corn, wheat and soybean futures markets to be significantly different from zero, indicating a risk premium. Marcus (1984) criticized Carter et al. for having overstated the commodity weighting in the market portfolio. Then Baxter et al. (1985) used Marcus's model to replicate Dusak's work and their findings supported Dusak's work.

Most of the empirical testing of the existence of risk premiums in futures markets has been done on non-livestock futures markets, and its general conclusion is that risk premiums do not exist.

A resent article Fama and French (1987) analyzed livestock futures markets for the existence of risk premiums. Fama and French (1987) conclude that there is no significant risk premium or time-varying risk premium in the pork belly futures market or the live hog futures market, and that a portfolio of commodity futures is more likely to show evidence of risk premium than individual commodity futures. The result that a portfolio of futures is more likely to show evidence of risk premium seems to support Dusak's (1973) thoughts, because a portfolio of futures probably has a larger impact on the market portfolio than individual futures.

The conclusion from the literature is that there is very little support for the theory of normal backwardation and risk premiums are therefore not expected in major futures markets.

Leuthold and Hartmann (1981) used the semi-strong test form to test the efficiency of the live hog and the pork belly market from 1971 to 1977. They compared the futures markets to an econometric model which was designed to forecast prices from all available information. The test was to measure whether the futures market or the model came up with the best price forecasts. For both pork futures markets they found that the price forecasting model some times came up with the best price prediction. Leuthold and Hartmann then concluded that the pork belly and the live hog futures markets were not consistently semi-strong efficient.

Chapter III. Data sources

This chapter presents the data used in the analysis and also explains why prices on cuts and futures are converted from US dollars (USD) to Canadian dollars (CAD).

III.1 Spot and futures prices

Spot prices from the period January 1985 to December 1991 were obtained from Gainers Inc. Edmonton. The spot prices used in this analysis are weekly wholesale prices quoted in Chicago. As a note, Gainers Inc. commonly trades pork cuts on the Toronto market, but no record of Toronto pork cut prices exist. According to executives at Gainers, the Chicago prices converted to CAD at the current exchange rate, are a good approximation of the Toronto prices.

Futures prices on pork bellies and live hogs are weekly Wednesday prices from January 1985 to December 1991 on all the traded contract months. Pork belly futures prices are traded on the following contract months;

February,
March,
May,
July and
August.

Live hogs futures prices are quoted for the following contract months;

February,
April,
June,
August,
October and
December.

The source is CME. The prices are published in the CME Yearbook[5].

Data regarding transaction costs on the live hog futures market and the pork belly futures market were obtained from Burns and Fry Limited, Edmonton.

III.2 Price units and currency

Pork cut and futures prices are normally quoted in cents per pound, however in this thesis prices are quoted in dollars per pound. The main objective of this thesis is to produce a dollar price of risk reduction, hence using dollars per pound as a price unit allows mathematical consistence in formulas and analysis.

All prices are converted[6] to CAD and deflated with the Canadian consumer price index, so that the analysis is made using real Canadian prices. A question arises: why convert the cut and futures prices from USD prices to CAD?

According to the "law of one price" displayed below in equation (10), the real price of pork in the US is equal to the real price of pork in Canada multiplied by the exchange rate (E), where E = CAD/USD.

$$(10) \quad P_{Pork}^{CAN} = E * P_{Pork}^{US}$$

The profit of forward and futures contracts per pound is equal to the price change between the selling and buying price[7]. It then follows that the profit per pound in CAD equals the profit per pound in USD times the exchange rate. Alternatively the profit in USD equals the profit in CAD divided by the exchange rate (11):

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[5] The futures prices can be ordered on computer diskettes through Knight-Ridder Financial Group, Chicago. Tel: 1-800-621-5271.

[6] The Wednesday exchange rates from 1985 to 1991 are from the Bank of Canada Review.

[7] Detailed description later in section IV.2.

$$(11) \quad \Delta P_{pork}^{CAN} = \underline{E*\Delta P_{pork}^{US}} \quad \Leftrightarrow \quad \frac{1}{E}*\Delta P_{pork}^{CAN} = \underline{\Delta P_{pork}^{US}}$$

It follows from (11) that the profit per pound or the price change in US pork prices is different from the price change in US pork prices times the exchange rate, as pointed out in equation (12):

$$(12) \quad E*\Delta P_{pork}^{US} \neq \Delta P_{pork}^{US}$$

Equation (12) suggest that the risk on forward profits or futures profits is different from when it is calculated on profits in USD to when it is calculated on profits in USD times the exchange rate.

Since risk is a key factor in the analysis, all US prices in the following analysis are converted to real Canadian prices by adjusting the US prices for the exchange rate and the Canadian Consumer Price Index (CPI). The reason for adjusting the prices for the CPI is that the analysis is based on prices from 1985 to 1991. In order to use prices from different years in the same analysis it is necessary to compare them in the same unit.

Chapter IV. Methodology

The example in the introduction illustrated how the meat packer can be exposed to the risk between a forward sales price of a cut and the spot price of a cut at maturity of that forward contract. This chapter develops the methodology to identify the risk reduction and marginal price of risk that results from hedging forward contracts on futures contracts.

The scenario in the introduction described a food retailer that asks the meat packer for a four week forward contract on two cuts. Section IV.1 describes a method for simulating a series of forward prices on cuts. Next, section IV.2 describes how profits on forward contracts are calculated, based on the differences between simulated forward prices and actual spot prices at the expiry date of the simulated forward contracts. Section IV.4 show, how the risk on the series of forward contract profits is calculated.

Now, the meat packer wants to know how much of the risk on forward contracts can be reduced by hedging. In order to answer this, the profits of futures contracts which will be used for hedging the forward contracts are developed in section IV.3. Then risk on the futures profits is calculated in section IV.4. Risk of a portfolio of forward contracts and futures contracts, as a function of the hedge ratio, is also shown in section IV.4. Section IV.5 then derives the formula for the marginal price of risk as a function of increasing hedge ratio.

IV.1 Estimation and simulation of forward prices

According to executives at Gainers Inc. Edmonton, the forward pricing of pork cuts is done by experienced pork traders who mainly determine the forward prices from historical price movements, but a record of forward prices does not exist. The assignment in this section is then to simulate weekly forward prices from information

that would have been available to the buyer and seller at the time the price was negotiated. This means that the spot price at time t is adjusted for forecastable time series components, to estimate the price at **t+k**.

The literature on time-series analysis suggests that three forecastable components be taken into account when describing time-series data:

Cycles,
Trend and
Seasonality,

Hog cycles are not regarded as an usable element in determining forward prices here. A study by Dubgaard and Rasmussen (1989) concluded that they were not able to find a pattern in Danish hog cycles from 1968 to 1988, and they did not expect to find a pattern in hog cycles in other major hog markets. It is unlikely that business cycles caused significant influence on the pork cut prices from 1985 to 1991, because the US GNP[8] shows no major changes in economic activity from 1985 to 1990.

The reason for using trend in forecasting pork cut prices is the continuing rationalisation in meat production and processing, which reduces production costs and thereby reduces food prices. Trend is estimated from linear regression for real prices on time, shown below.

Linear regression equation for estimating price trend:

$$P_{Spot,t} = a + b^{*}t + e_t, \quad e_t \approx N(0,\sigma^2)$$

[8] International Financial Statistical Yearbook, IMF, 1991

Variables used for estimating trend:

$P_{Spot,t}$ = spot price at week **t**,

a = intercept term,

t = week number, the first week in 1985 is week 1, t=1,2,3,,,,365,

b = slope of the regression line, weekly spot price trend,

e_t = error term.

The trend estimated above is estimated from the weekly pork cut prices from 1985 to 1991. However, this trend is used to simulate forward prices in the same period. This means that information is used to predict prices on forward contracts, not available at the time the forward price was negotiated. The reason is that the only data set available on the pork cut prices is the set of prices from 1985 to 1991.

The estimated trend may not only be a result of reduced costs in the pork meat industry. The estimated trend is more likely a combination of reduced costs in the pork meat industry and non forcastable factors, such as cycles and irregular price movements.

Seasonality is considered as being an important factor in determining the forward price of pork cuts, because consumers eating habits change from season to season.

Estimation of a seasonality index:

The weekly seasonality index (WSI) for week **t** is then calculated on the prices adjusted for trend.

$$(13) \quad WSI_t = \frac{52 * \sum_{year}^{7} P_{tr(year,t)}}{\sum_{year}^{7} \sum_{week}^{52} P_{tr(year,t)}} * 100$$

where;

$P_{tr,t} = P_{Spot,t} - (b*t)$, $t=1,2,3,,,,365$. Prices adjusted for trend.

It is assumed that trend and seasonality are independent of each other, so that the seasonal variation for each week is the same every year.

Simulation of forward prices:

The forward prices **k** weeks ahead ($P_{Forw=k,t}$) at week **t** are simulated from the spot prices, seasonality index and trend:

$$(14)\ P_{Forw=k,t} = (P_{Spot,t} + (b*k)) * (WSI_{t+k}/WSI_t),\ t=1,2,3,,,365-k$$

Equation (14) is used to simulate weekly forward prices from 1985 to 1991. The simulated forward prices are used to identify the weekly forward profits in the next section.

IV.2 Simulation of profits of forward contracts

Profit per pound on a forward contract is calculated every week from 1985 to 1991. A contract is presumed to be negotiated every week at the simulated forward price. The profit on a contract is found by comparing the forward price to the spot price **k** weeks later. For example, the first four week contract is sold in the first week of January 1985 at the four week forward price calculated in the first week of January 1985. Profit on this contract is calculated in week 5, 1985 using the spot price in week 5, 1985. The second four week contract is sold in week 2, 1985 and compared to the spot price in week 6, 1985 etc. Nine week contracts are simulated in a similar way, the first contract is sold in first week of January 1985 at the nine week forward price calculated in the first week of January 1985, this contract is compared to the spot price in week 10, 1985 etc.

The profit per pound of a **k** week forward contract at time **t** is:

(15) $PRO_{Forw=k,t} = P_{Forw=k,t} - P_{Spot,t+k}$, $t=1,2,3,,,365-k$

where;

$P_{Forw=k,t}$ = forward price **k** weeks ahead,

$P_{Spot,t+k}$ = spot price **k** week ahead.

The profit terms above are absolute profit terms measured in dollars per pound. Finance literature often uses profit measured in relative terms, as a return on investment. The analysis in this thesis will be based on relative profit terms.

Relative profit on a **k** week forward contract is defined as:

(16) $\pi_{Forw=k,t} = PRO_{Forw=k,t} / P_{Forw=k,t}$, $t=1,2,3,,,365-k$

Forward contract profits are obtained during 1985-91. The next step is to simulate the futures profits for the same period, so that hedging forward contracts on the futures market can be analyzed.

IV.3 Identification of profits of futures contracts

A futures contract is bought every week and is sold **k** weeks later. A hedge can be made every week for a period of **k** weeks ahead. The nearest futures contract with minimum **k+4** weeks to maturity is always chosen. This leaves **k** weeks for the hedge and makes it possible to terminate the futures contract four weeks before maturity. The trade in a futures contracts is terminated 4 weeks before maturity in order to avoid procedures for physical delivery.

Example of how four week futures contracts in pork bellies are generated:

The first four week futures contract is bought in week 1-1985 in the April-contract-1985 and is sold in week 5-1985. The second four week futures contract is bought in

week 2-1985 in the April-contract-1985 and is sold in week 6-1985. The buying in the April-1985 contract continues until week 8-1985. In week 8-1985 the last April futures contract is bought because the April-contract-1985 has maturity in week 16-1985. This leaves 4 weeks to end the selling in the contract before the delivery procedure starts 4 weeks before maturity. After week 8 the buying continues in the June-contract-1985, and the process continues.

The profit of the k week futures contract ($PRO_{Fut,t}$) in week t is:

(17) $PRO_{Fut,t+k} = P_{Fut,t+k} - P_{Fut,t}$, $\quad t=1,2,3,,,365-k$

where;

$P_{Fut,t+k}$ = futures price **k** week ahead of week **t**, of the nearest futures contract with min. **k+4** weeks to expiry.

$P_{Fut,t}$ = futures price in week **t**, of the nearest futures contract with min. **4** weeks to expiry.

As with the forward profits the profits of the futures contracts are measured in relative values.

Relative profit on a **k** week futures contract is defined as:

(18) $\pi_{Fut,t} = PRO_{Fut,t+k} / P_{Fut,t}$, $\quad t=1,2,3,,,365-k$

As with the forward profits the futures profits are identified during 1985-91.

After having gone through how the forward and the futures profits are simulated, the next two steps show how these profits are used to reach the main goals of the whole analysis; risk reduction and the cost of risk reduction.

IV.4 Calculation of risk

There are two possible risk measures of forward contracts and futures contracts. Standard deviation (Stdev.) or the square Root of the Mean Square Errors (RMSE). The difference between RMSE and Stdev. is that RMSE measure the deviation from expected values where stdev. measure the standard deviation around the mean of the observations. The two risk measures coincide if the mean forms the expectations. Equation (19) shows the formula for the standard deviation;

$$(19) \quad Stdev = \sqrt{\frac{\sum_1^n (\pi_t - \overline{\pi})^2}{n}} \qquad t = 1,2,3,,,n$$

Equation (20) is the formula for RMSE when the profit is expected to be zero;

$$(20) \quad RMSE = \sqrt{\frac{\sum_1^n (\pi_t - 0)^2}{n}} \qquad t = 1,2,3,,,n$$

RMSE is preferred to Stdev. as the risk measure, because RMSE form an expectation about the obtainable profit on the forward or futures market, whereas Stdev. implicitly assumes that expected profit is equal to the mean of historical profits. Hence, RMSE can be based on more information than the Stdev., because RMSE can take both historical information and other information into account.

In the case of risk premiums in futures markets, discussed in chapter II, it was concluded that risk premiums should not be expected. This means that the profit of futures markets is expected to be zero. Hence, the RMSE with expectation of zero profit should be used as a risk measure.

The risk of the combined portfolio of forward and futures contracts is;

$$(21) \quad Stdev_{Forw,Fut} = \sqrt{\sigma^2_{Forw} + HR^2 * \sigma^2_{Fut} + 2 * HR * \sigma_{Forw,Fut}}$$

where;

HR = **H**edge **R**atio = value of the futures position / value of the forward position.

If the expected profit of forward and futures contracts is zero, the total risk of the forward and futures contracts is:

$$(22) \quad RMSE_{Forw,Fut} = \sqrt{MSE_{Forw} + HR^2 * MSE_{Fut} + 2 * HR * \sigma_{Forw,Fut}}$$

where;

$MSE = RMSE^2$.

If equation (22) forms the risk measure the covariance ($\sigma_{Forw,Fut}$) between the relative forward profits and the relative futures profits is defined as:

$$(23) \quad \sigma_{Forw,Fut} = \frac{\sum_1^n (\pi_{Forw,t} * \pi_{Fut,t})}{n} \qquad t = 1,2,3,,,n$$

With equation (21) as the risk measure the covariance ($\sigma_{Forw,Fut}$) is defined as:

$$(24) \quad \sigma_{Forw,Fut} = \frac{\Sigma_1^n (\pi - \overline{\pi})_{Forw,t} * (\pi - \overline{\pi})_{Fut,t}}{n}$$

By changing the hedge ratio in (21) and (22) the risk changes and the result is a set of risk and hedge ratio combinations.

IV.5 The marginal cost of risk reduction

The cost of risk reduction is an important indicator for the meat packer in making hedging decisions.

Transaction costs on the futures markets include brokerage and lost interest on initial margins. Brokerage and initial margin are flat rates. In order to compare the transaction costs to the risk reduction, the transaction costs have to be measured in relative costs, since the risk reduction is measured on relative profits. The relative transaction costs change if the brokerage, initial margin, risk free interest rate or the current futures price change.

Brokerage is as mentioned a flat rate. If the price of the futures contract goes up and the brokerage is unchanged, then the relative transaction costs goes down. The opposite happens when the current futures price goes down. For example the brokerage is 100 $ per contract and a contract is 40,000 pound and the current futures price is 0.5 $ per pound, then the relative brokerage is; 0.005. If the current futures price goes up to 0.55, then the relative brokerage goes down to 0.0045.

Initial margin is also a flat rate, and the lost interest on the initial margin is also converted to a relative value. Initial margin is security deposit, which all futures trader have to make before they start trading, it is paid back when the futures positions are closed. The clearing house does not pay interest on the initial margin,

so the futures trader loses interest on the initial margin deposit. It is assumed that the alternative cost of the lost interest is the risk free interest rate, equivalent to the short term interest on government bonds. The change in the relative transaction costs resulting from lost interest on the initial margin is dependent on the changes in risk free interest rate, changes in the initial margin and changes in the current futures price. If for example the initial margin or the risk free interest rate goes up and the current futures price a constant then the relative transaction costs goes up. The lost interest of initial margin does not count for more than 3% to 10% of the total transaction costs. Hence, changes in the risk free interest rate or the initial margin does not affect the total transaction costs much.

If the relative value of the transaction costs are artificially held constant, the price of risk is a function of the hedge ratio. Higher hedge ratio means a higher proportion of futures in the portfolio of futures and forward contracts. Hence, the cost of risk reduction is an increasing function of the hedge ratio.

The following shows how the marginal cost of risk is derived algebraically if no risk premium is expected and RMSE is used as risk measure. First, the transaction costs are listed. Next, the transaction costs are converted to transaction costs per pound and inserted in the total relative cost formula, equation (25). Total costs are converted to total relative costs per dollars of futures contract. Since the risk is calculated from relative profits, the costs are also calculated in relative value. Total relative costs are a linear function of the hedge ratio assuming that the ratio of transaction costs to futures price is artificially held constant. Finally the marginal cost of risk reduction is shown as the change in total relative cost divided by the change in the total risk.

Transactions costs:

B = Brokerage per futures contract, $,

M = Initial margin per futures contract, $,

$I_{F,k}$ = Risk free interest rate per k weeks, %,

Transaction cost inserted in the cost formula:

Bp = B/pound per futures contract, $/lb.,

Mp = (M * $I_{F,k}$/100)/(pound per futures contract), $/lb.,

T_c = (Bp + Mp), total transaction cost per pound, $/lb,

$P_{Fut,now}$ = current price of the futures that the hedging will be done in, $/lb,

(25) $TT_c = (HR/P_{Fut,now}) * T_c$, total relative transaction cost, $

The marginal cost of risk reduction when transaction costs and the current futures price are constant:

$\Delta TT_c = \Delta HR/\overline{P}_{Fut,now} * \overline{T}_c$ change in total relative transaction costs,$.

$\Delta RMSE_{Forw,Fut}$ = change in total risk,

Price of Risk Reduction, or the marginal cost of risk reduction:

$$(26) \quad P_{RR} = \frac{\Delta TT_c}{\Delta RMSE_{Forw,Fut}} = \frac{\frac{\Delta HR}{\overline{P}_{Fut,now}} * \overline{T}_c}{\Delta RMSE}$$

If a risk premium is expected, the risk premium per pound is added to (25). The risk measure is this case is RMSE, equation (21), where the expected mean of the futures

profits is equal to the risk premium.

The price of risk as a function of the hedge ratio shifts position if the transaction costs, the current futures price, the risk of forward contact profits or the risk of futures contract profits change. If these factors are held constant then the marginal costs of risk reduction is an increasing function of the hedge ratio.

In order to improve the meat packers hedging decision, the marginal unit of risk is supplied with a confidence interval. Since transaction costs are not subject to risk, it is the RMSE that produces the confidence interval. The confidence interval of the $RMSE_{Forw,Fut}$ is[9];

$$(27)\quad \sqrt{\frac{(n-1)\cdot MSE_{Forw,Fut}}{\chi^2_{(\alpha/2,df)}}} \le RMSE_{Forw,Fut} \le \sqrt{\frac{(n-1)\cdot MSE_{Forw,Fut}}{\chi^2_{(1-\alpha/2,df)}}}$$

$$\rightarrow \qquad RMSE_{Low} \le RMSE_{Forw,Fut} \le RMSE_{High}$$

where
df = degrees of freedom.

The upper and the lower bound of the confidence interval of the price of risk reduction is;

$\Delta TT_c / \Delta RMSE_{Low}$, upper confidence bound of the price of risk,
$\Delta TT_c / \Delta RMSE_{High}$, lower confidence bound of the price of risk.

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[9] Source: Harnett D.L. (1982) Statistical Methods. 3rd ed. P. 331-33

IV.6 Risk reduction and length of the forward period

Changing **k** in the analysis allows analysis of risk reduction and cost of risk reduction for different forward periods. The forward periods used in this analysis are, four weeks and nine weeks. The reason for using four week and nine week forward periods is that Gainers Inc. find these periods interesting for forward contracting.

Chapter V. Results

This chapter presents the results of the analysis described in chapter IV applied to the data described in chapter III. Section V.1 presents the trend and seasonality of belly and loin spot prices. The last part of section V.1 presents the risk of the simulated four week and nine week forward profits. Then section V.2 presents the risk of the four week and nine week futures profits. Finally Section V.3 shows the risk reduction from hedging of four week and nine week belly and loin forward contracts. Section V.3 also shows the marginal costs of risk reduction function from hedging of four week and nine week belly and loin forward contracts.

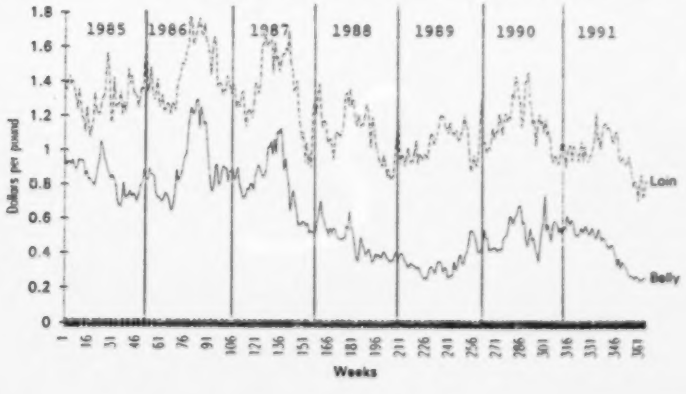
V.1 Forward contracts

The technical names for the cuts are; 12-14bellies and 12-14loins. Bellies are the two pieces of meat on the underside of a hog. The code 12-14, refers to the cut weight in pounds.

V.1.1 Trend and seasonality on belly and loin spot prices

Chart 1 show the movement in real prices of the cuts. Some of the local price movements are similar for both cuts, and the overall trend is declining prices, where bellies have declined most in price.

Chart 1. Weekly spot price of belly and loin, 1985-91.



The drop in belly prices in 1988 and 1991 is explained by traders in the US pork market as a result of unexpected increase in hog production combined with a decrease in bacon consumption. A weaker picture of this price pattern can be seen in loin prices. It is mostly the production increase in hog production that has caused the price drop in loin prices in 1988 and 1991, since demand for loins has been relatively stable. Table 1 presents the estimate of the price trends from 1985 to 1991, which are used in the simulation of the forward prices.

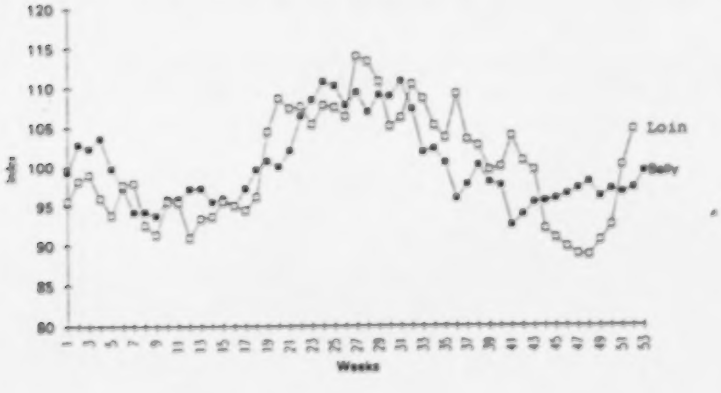
Table 1. Weekly price trends on bellies and loins.

	Weekly trend	t-stat	R^2
Bellies	-0.00169 $/lb	- 37.5***	0.54
Loins	-0.00130 $/lb	- 15.5***	0.40

*** = significant at 1% level.

Chart 2 shows the weekly seasonality index's for each cut. The seasonality pattern of the prices appears similar for both cuts. Prices peak over the summer and bottom out around February and March, October and November, with a small peak around Christmas.

Chart 2. Weekly seasonality index of belly and loin prices.



V.1.2 Results of simulating profits of forward contracts

Table 2 and 3 presents the mean and the risk of the relative profits of four week and nine week belly and loin forward contracts.

Table 2. Mean and risk of the relative profits of four week belly and loin forward contacts.

	Mean.	Stdev.	RMSE
Bellies	-0.00934	0.14922	0.14951
Loin	-0.00181	0.08144	0.08146

Table 3. Mean and risk of the relative profits of nine week belly and loin forward contracts.

	Mean.	Stdev.	RMSE
Bellies	0.0104	0.19296	0.19323
Loin	-0.0023	0.10422	0.10424

The significance of the means in table 2 and 3 can not be tested by the standard t-test, because the profits are non-independent, they overlap each other in time. For example every four week profit observation is overlapped by the following three profit observations.

The mean of the forward profits is relatively low compared to the standard deviation so the means are probably not significantly different from zero. However, the profits of the forward contracts are generated from the simulated forward prices. The average trend and the average seasonality during 1985-91, are used to simulate the forward prices in the same period. This guarantee that the average profit of forward contracts from 1985 to 1991 is zero.

The profits of the forward contracts are not expected to deviate systematically from

zero. This means that the RMSE with expected profit of zero is the risk measure that is used on the forward contracts.

Chart 3 to 6 shows the plot of the four and nine week forward profits on bellies and loins.

Chart 3. Relative profits on four week belly forward contracts, weekly observations 1985-91.

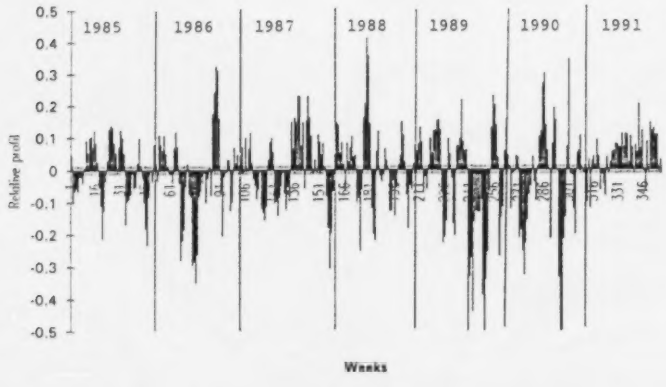


Chart 4. Relative profits on four week loin forward contracts, weekly observations 1985-91.

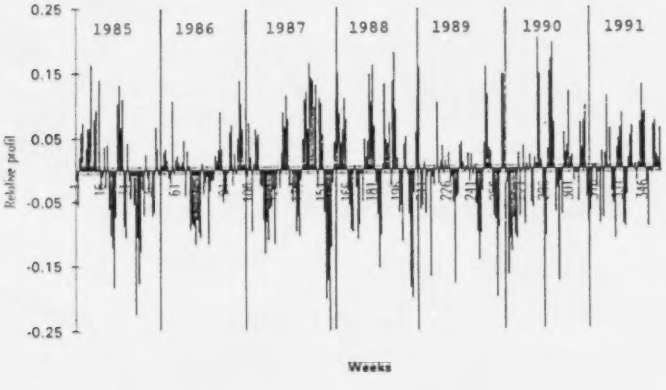


Chart 5. Relative profits on nine week belly forward contracts, weekly observations 1985-91.

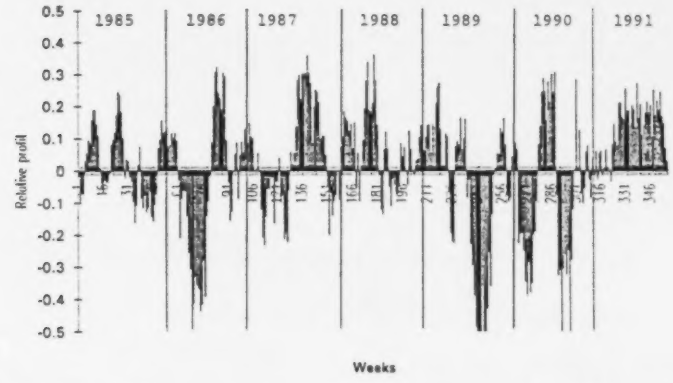
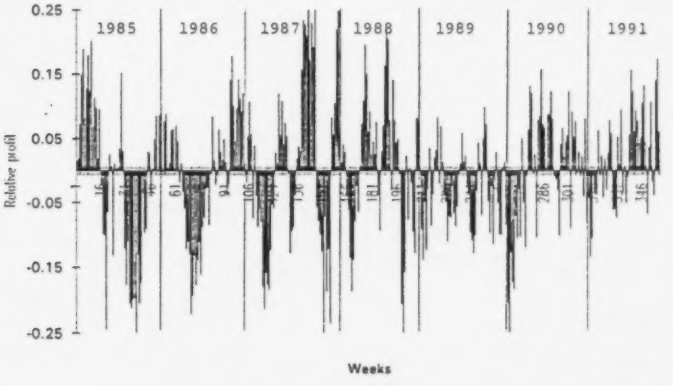


Chart 6. Relative profits on nine week loin forward contracts, weekly observations 1985-91.



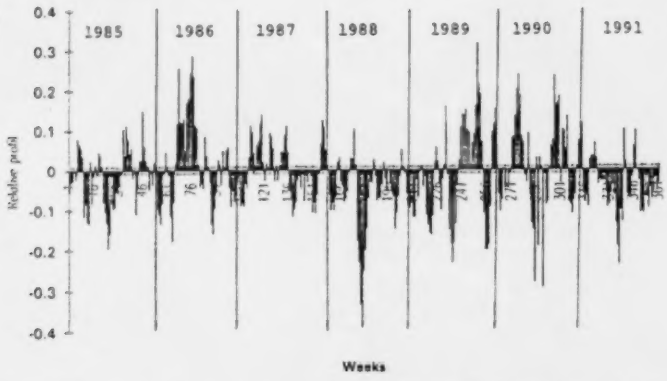
V.2 Futures contracts

Pork bellies and live hogs on CME are traded in contracts of 40,000 pounds. The trading units on pork bellies are 12-14 pounds, 14-16 pounds and 16-18 pounds. A live hog is a 230-260 pounds barrow or gilt.

V.2.1 Results from profits on four week pork belly contracts

Continuously weekly buying and selling of four week pork belly contracts from 1985 to 1991 produces 361 relative profit observations. All the relative profits are plotted in chart 9.

Chart 7. Relative profits on four week pork belly futures contracts, weekly observations 1985-91.



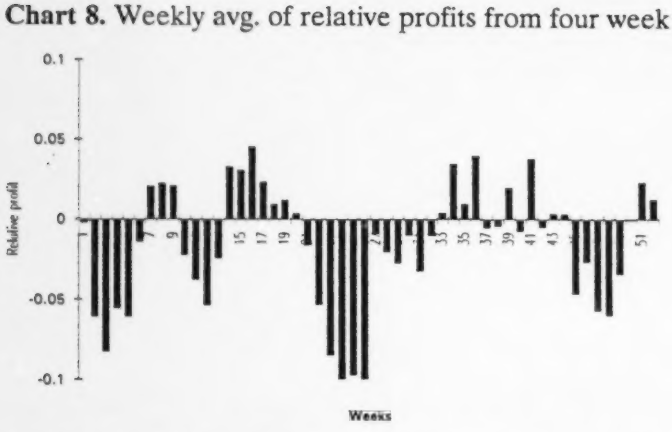
1988 and 1991 are outstanding years, because they are characterized by almost constant losses. Traders in the US pork industry explain these losses by a combination of unexpected increases in the pork production and declining demand for bacon.

The mean and standard deviation of the 361 relative profits are;

Mean = -0.0158 and
Stdev.= 0.1009

Chart 7 indicates that some years have a similar pattern in profits in certain periods. Chart 8 can be used to analyze this pattern in the profits. Chart 8 show the average of the weekly profits. Every observation in chart 8 is the weekly average of the profits of the futures contracts from 1985 to 1991 etc. The first observation is the average of all the futures contracts started in week 1 and terminated in week 5 every year from 1985 to 1991, it is almost zero. The week numbers in chart 8 refers to the week a contract is bought.

Chart 8. Weekly avg. of relative profits from four week pork belly futures contracts.



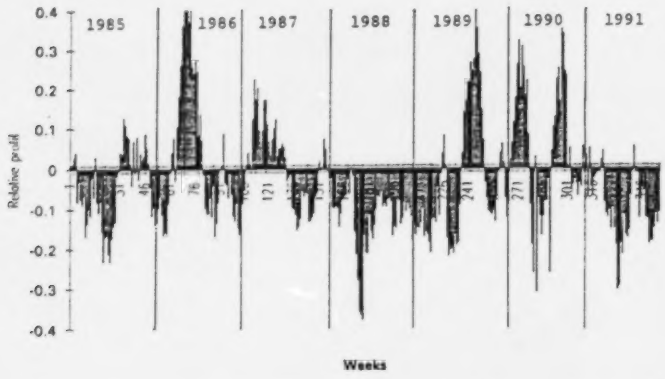
According to the literature it should not be expected to find risk premiums in the pork belly futures market, but the average profits from week 22 to week 26 are relatively high. Section A.I.1 in the appendix analyzes the profits from four week pork belly contracts closer.

The tests in section A.I.1 supports the hypothesis that the mean of the profit is not significantly different from zero. On the other hand, an economic interpretation of what is going on form week 22 to 26 argues that there could have been a negative risk premium in past years during week 22-26. Section A.I.1 concludes, with support from the literature that risk premiums should not be expected in the future in the pork belly futures market.

V.2.2 Results from profits of nine week pork belly contracts

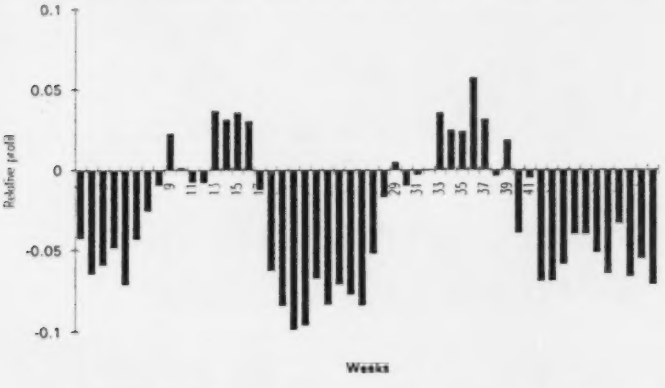
Continuously weekly buying and selling of nine week futures contracts from 1985 to 1991 produces 356 profit observations. These profits are plotted in chart 9. As it was seen in chart 7 for the profits of four week profits on pork belly contracts, 1988 and 1991 are characterized by almost constant losses.

Chart 9. Relative profits on nine week pork belly futures contracts, weekly observations 1985-91.



The profits indicates that some years have a similar pattern in profits in certain periods. This is examined closer in chart 10, because chart 10 show the average of the weekly profits.

Chart 10. Weekly avg. of relative profits from nine week pork belly futures contracts.



As with the four week pork belly contracts the plot of average profits (chart 10) indicates high losses from week 18 to week 27, section A.I.2 in the appendix examines this. The conclusion in section A.I.2 is the same as the conclusion in A.I.1, where it is concluded that risk premiums should not be expected in the future.

The mean and the standard deviation of the 356 profits are;

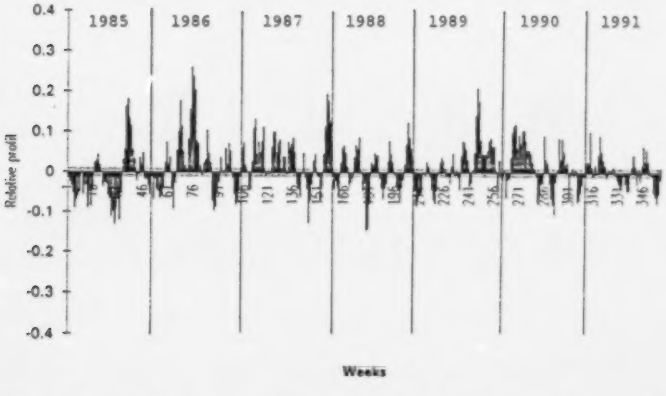
Mean = -0.0287 and
Stdev. = 0.1444

Both the four week profits and the nine week profits have a negative mean. The annualized mean is -0.22 on the four week pork belly profits and -0.18 on the nine week pork belly profits. The nine week mean is relatively closer to zero than the four week mean.

V.2.3 Results from profits on four weeks live hog contracts

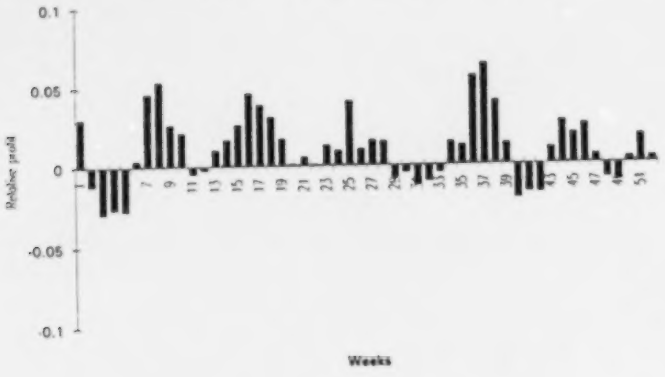
The 361 profit observations from weekly trading in four week live hog futures are plotted in chart 11. Apart from a few clusters of large profits in the middle of 1986 and in the fall of 1989 and in the and of 1987, the profits are relatively even distributed around zero.

Chart 11. Relative profits on four week live hog futures contracts, weekly observations 1985-91.



The plot of the average weekly profits from 1985 to 1991 (chart 12), show that there has been positive profits from week 6 to 28. Section A.I.3 in the appendix analyses the profits for evidence of risk premiums. The conclusion from section A.I.3 is that, risk premiums should not be expected in the live hog futures market.

Chart 12. Weekly avg. of relative profits from four week live hog futures contracts.



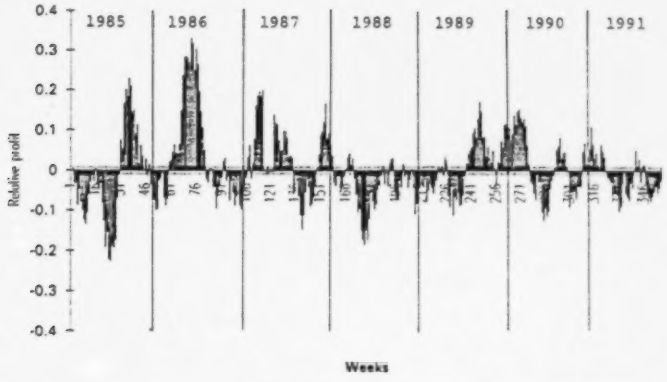
The mean and standard deviation of the 361 profit observations are;
Mean = 0.0108 and
Stdev. = 0.0646

This standard deviation is less than the standard deviation for four week pork belly futures profits. This relationship between the four week and nine week risk is primarily due to the economic differences between the two commodities. The supply of both commodities is the same, however demand is different. The demand for live hogs is dependent on demand for several different pork products, whereas the demand for bellies is only dependent on demand for one final product, bacon. This makes belly prices more sensitive to market changes than hog prices.

V.2.4 Results from profits on nine week live hog contracts

Chart 13 presents the 356 profit observations from nine week live hog futures trading. As with the four week live hog futures profits, a large cluster of high profits can be observed in 1986. Profits in 1988 and 1991 is dominated by losses, probably because of the unexpected increase in hog productivity mentioned earlier.

Chart 13. Relative profits on nine week live hog futures contracts, weekly observations 1985-91.



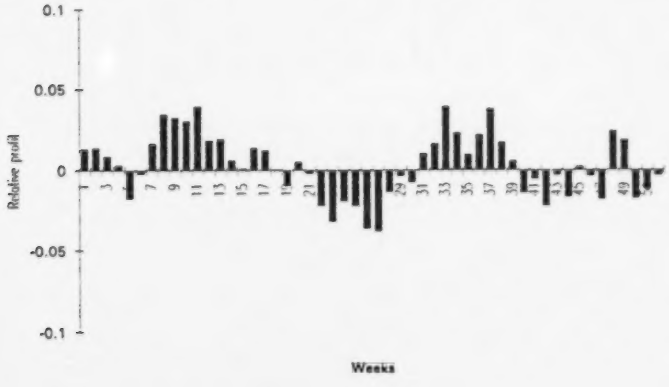
The mean and standard deviation of the 356 profit observations are;

Mean = 0.0027 and

Stdev. = 0.0938

The mean is relatively close to zero and the plot of the average weekly profits (chart 14) shows neither high positive average profits nor low negative average profits.

Chart 14. Weekly avg. of relative profits from nine week live hog futures contracts.



V.2.5 Conclusion on futures contracts

The analysis in the appendix does not suggest that a buyer of futures contract should expect risk premiums in the two futures markets. If the meat packer nevertheless expect negative risk premiums in a certain hedging period in the pork belly futures market, then section VI.1 explains what the meat packer should do. Section VI.1 show how much negative risk premium the meat packer can accept before the price of risk reduction become too high in pork belly market compared to the price of risk reduction in the live hog futures market.

Since profits on the two futures markets is expected to be zero, the RMSE will be used as the risk measure of risk for profits on futures contracts.

Table 4. RMSE on relative futures profits.

Futures contracts	RMSE
4 week pork belly	0.10215
9 week pork belly	0.14723
4 week live hog	0.06510
9 week live hog	0.09360

V.3 Hedging results

This section presents the results of hedging four week and nine week forward contracts of bellies and loins on the pork belly and the live hog futures markets.

For each forward contract a chart will show the reduction in total risk that can be achieved by hedging, on either the pork belly futures markets or the live hog futures market. For each forward contract a chart will show the marginal unit cost of risk reduction function that is a function of hedging. Appendix A.II contains the tables of the hedging results for each forward contract.

The risk reduction functions reaches a minimum at the optimal hedge ratio without transaction costs, equation (5). This optimal hedge ratio and the corresponding total risk of the forward and futures portfolio is indicated on the charts. This shows the minimum obtainable total risk of the forward and futures portfolio.

Each marginal unit cost of risk function is supplied with a 95% confidence interval. This is illustrated by the dotted lines in the charts. The confidence interval is obtained by calculating the confidence interval on the RMSE. This produces a confidence interval on the RMSE that is a function of the hedge ratio, since the RMSE is a function of the hedge ratio. Each side of the confidence interval of the marginal cost of risk function is then, the change in cost divided by the change in each side of the RMSE confidence interval as a function of the hedge ratio.

The calculation of the total relative transaction costs is based the transaction costs and current futures prices contained in table 5. The quotation date for the transaction costs and the current futures price is August 12, 1992.

Table 5. Transaction costs and current futures prices used in the calculation of the marginal price of risk reduction function. Date of quotation is August 12, 1992.

	Pork Belly futures	Live Hog futures
Brokerage $/contract	107	107
Margin req. $/contract	1782	832
Bp = Brokerage $/lb	0.002675	0.002675
Mp4= Margin cost for four weeks. $/lb	0.00020	0.000094
Mp9 = Margin cost for nine weeks. $/lb	0.00045	0.00021
$P_{Fut=4,now}$ = futures price four weeks away	0.38	0.39
$P_{Fut=9,now}$ = futures price nine weeks away	0.38	0.405

One futures contract is 40,000 pounds.

Exchange rate: 0.8417 USD/CAD

Risk free interest rate: 6% p.a. = 0.45% per four week and 1.01% per nine week.

The transaction costs are then used in equation (25) from chapter IV, reproduced below;

(25) $TT_c = (Bp+Mp)*HR/P_{Fut=k,now}$, total relative transaction costs

Equation (25) for the four week pork belly futures look like this;

$$TT_c = (0.002675 + 0.0002)*HR/0.38$$

As explained in IV.5, the marginal cost of risk reduction function shifts position when the current futures price, brokerage margin requirements and the risk free interest rate changes. Brokerage, margin requirements and the risk free interest rate does not

change often, but the current future price ($P_{Fut,now}$) change from day to day. Hence, the total relative cost function change from day to day. Hence, the marginal cost of risk reduction function shift position from day to day. The correct way to present the price of risk reduction functions is to show a family of marginal price of risk reduction functions. That has not been completed because the charts become complicated with several price of risk functions and confidence intervals. Instead it will be shown how the price of risk reduction function shifts when the relative transaction cost change in section V.3.1. The reader should note that the marginal price of risk reduction functions and the tables in section A.II in the appendix are instantaneous. The tables in section A.II therefore need to be updated for every change in the transaction costs and the current futures price.

V.3.1 Hedging of four week pork belly forward contracts

By hedging a four week belly forward contract on the pork belly futures the total risk can be reduced from 0.1495 to a minimum risk of 0.1074 at a hedge ratio of 1.02. Whereas the total risk can be reduced to a minimum of 0.1288 at a hedge ratio of 1.17, when a four week belly forward contact is hedged on the live hog futures market. Chart 15 and 16 show the reduction on total risk from hedging a four week belly forward contract on the pork belly futures and live hog futures markets.

Chart 15. Risk when four week belly forward contracts are hedged on pork belly futures contracts.

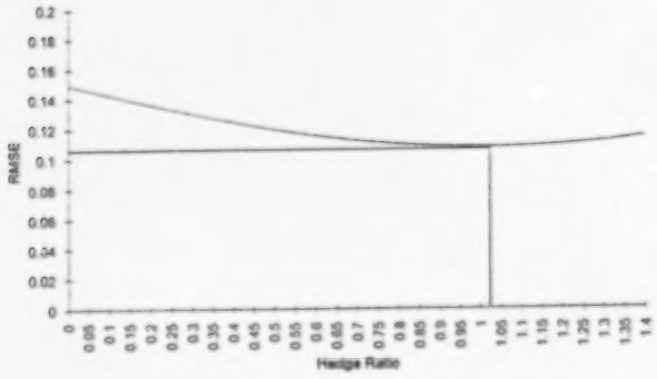
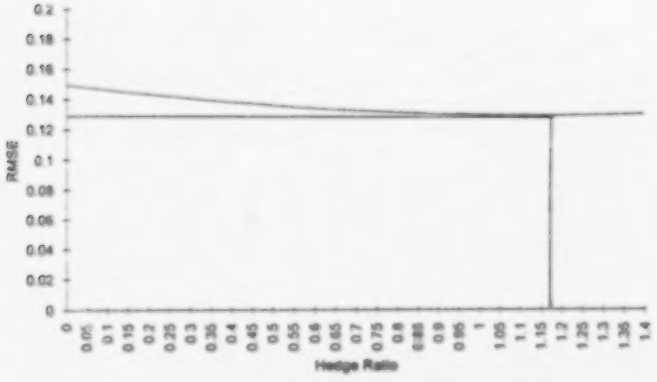


Chart 16. Risk when four week belly forward contracts are hedged on live hog futures contracts.



It is not surprising that the risk reduction is greatest when a belly forward contract is hedged on the belly futures market. It is perhaps a little surprising that the risk reduction is not higher, as the definition of the two contracts is close and they are both quoted on markets in Chicago.

Chart 17 and 18 show the marginal price of risk reduction functions for a belly forward contact hedged on the pork belly futures market and the live hog futures market. The two dotted lines in each chart represent the 95% confidence interval.

Chart 17. Marginal price of risk reduction function. Four week belly forward contracts hedged on the pork belly futures.

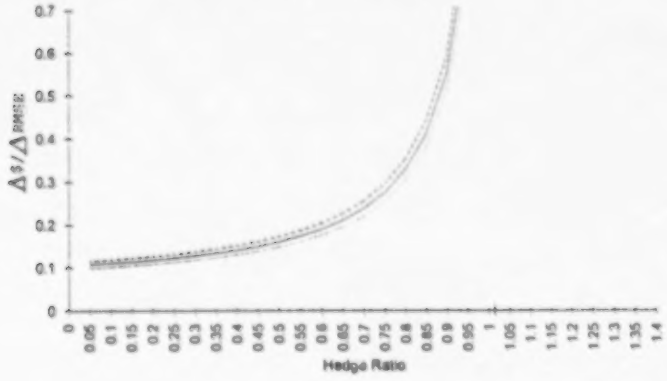
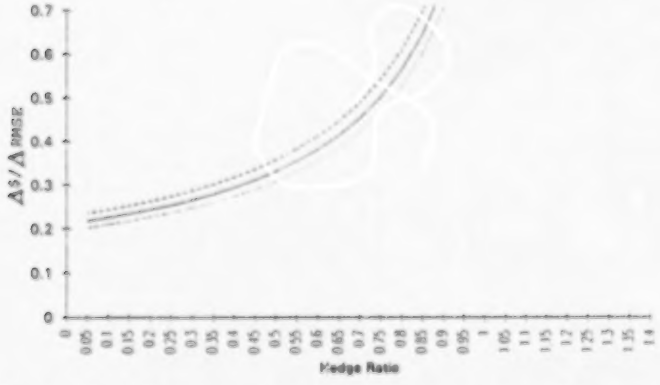


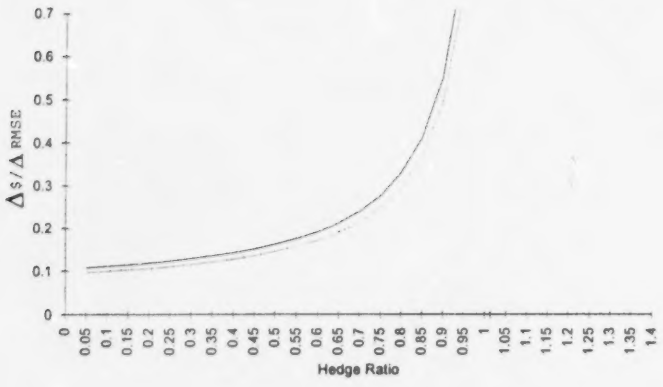
Chart 18. Marginal price of risk reduction function. Four week belly forward contracts hedged on the live hog futures.



The price of risk reduction is lowest when a four week belly forward contract is hedged on the pork belly futures market, because the reduction in total risk is highest on the pork belly futures market.

Chart 19 shows how the marginal price of risk reduction function shift if the relative transaction cost change by 10%. In most case this is caused by a change in the current futures price or the brokerage. According to the broker firm Burns and Fry, the brokerage will be reduced if hedger hedges more than 100 contracts. Since the transaction costs per contract is declining with the amount of contracts traded.

Chart 19. Shift of the price of risk reduction function when relative transaction costs changes by 10%. Four week belly forward contracts hedged on the pork belly futures.



The message from chart 19 is, that the calculation of the price of risk reduction should be kept up to date.

V.3.2 Hedging of four week loin forward contracts

The total risk of a four week loin forward contract can only be reduced from 0.0814 to a minimum of 0.0802 by hedging it on the pork belly futures market. The total risk can be reduced a little more on the live hog futures market. On the live hog futures market it can be reduced to 0.0737 at a hedge ratio of 0.53.

Chart 20. Risk function when four week loin forward contracts are hedged on belly futures contracts.

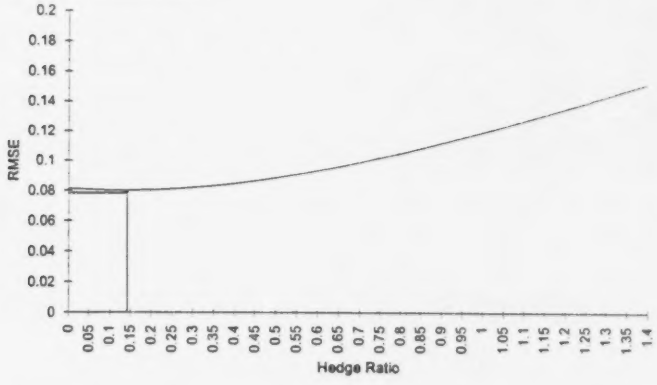


Chart 21. Risk function when four week loin forward contracts are hedged on live hogs futures contracts.

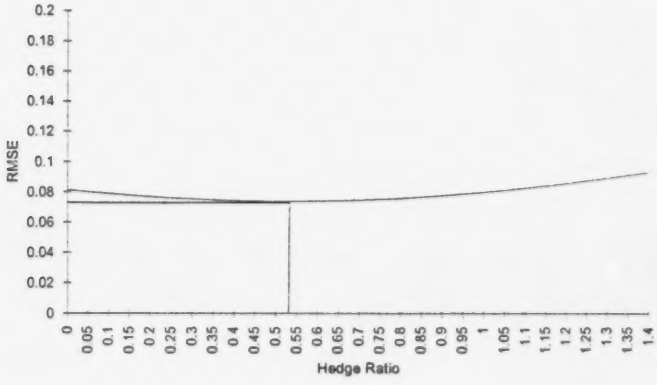


Chart 22 and 23 show the marginal price of risk reduction functions from hedging a four week loin forward contract on the pork belly and the live hog futures markets.

Chart 22. Marginal price of risk reduction function. Four week loin forward contracts hedged on the pork belly futures.

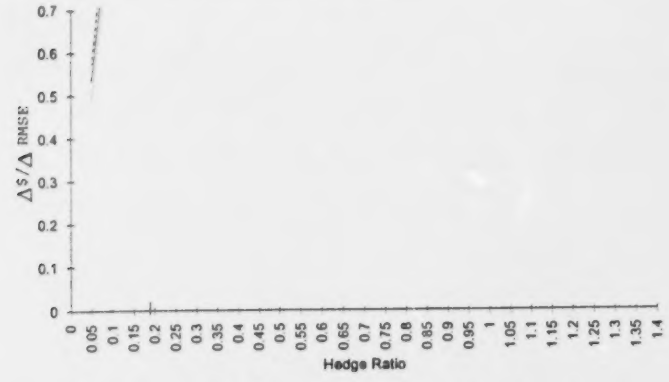
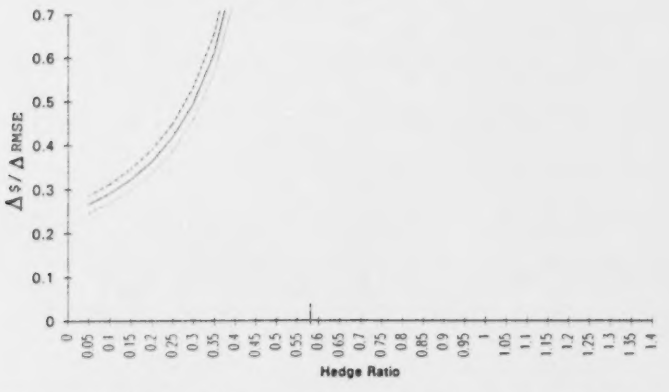


Chart 23. Marginal price of risk reduction function. Four week loin forward contracts hedged on the live hogs futures.



The marginal prices of risk reduction of a four week loin forward contract is significantly higher in the pork belly futures market than the live hog futures market.

V.3.3 Hedging of nine week belly forward contracts

By hedging a nine week belly forward contract on the pork belly futures market, the total risk can be reduced from 0.193 to a minimum risk of 0.1142 at hedge ratio of 1.06. On the other hand, total risk can only be reduced to a minimum of 0.1452 at a hedge ratio of 1.36 if the nine week belly forward contract is hedged on the live hog futures market. Chart 24 and 25 show the risk reduction functions for a nine week belly forward contract hedged in the two futures markets.

Chart 24. Risk when nine week belly forward contracts are hedged on pork belly futures contracts.

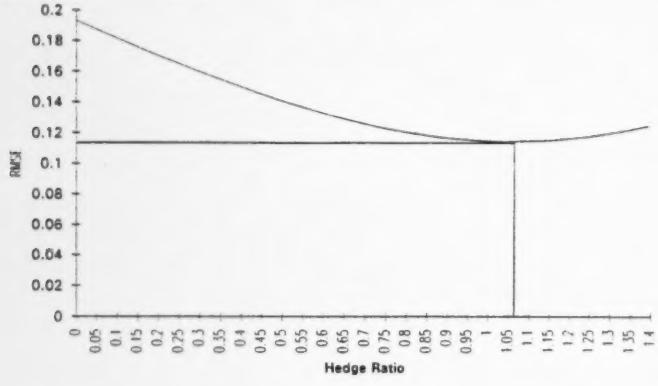


Chart 25. Risk when nine week belly forward contracts are hedged on live hog futures contracts.

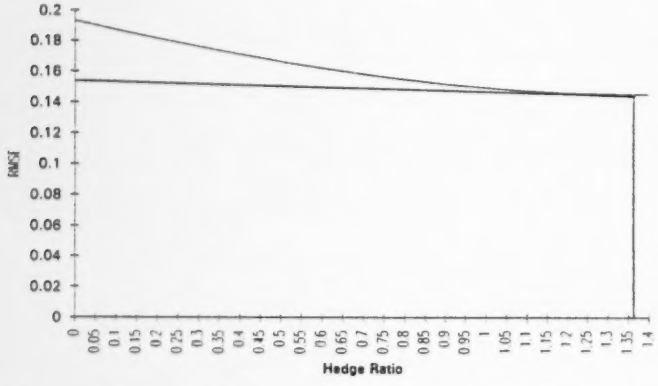


Chart 26 and 27 show the marginal price of risk reduction functions for a nine week belly forward contract hedged on the pork belly futures market and the live hog futures market.

Chart 26. Marginal price of risk reduction function. Nine week belly forward contracts hedged on the pork belly futures.

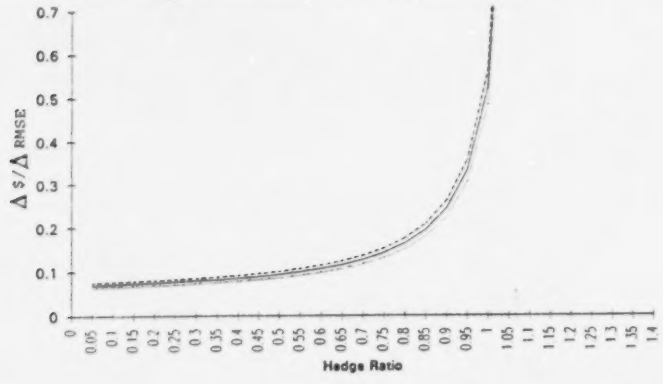
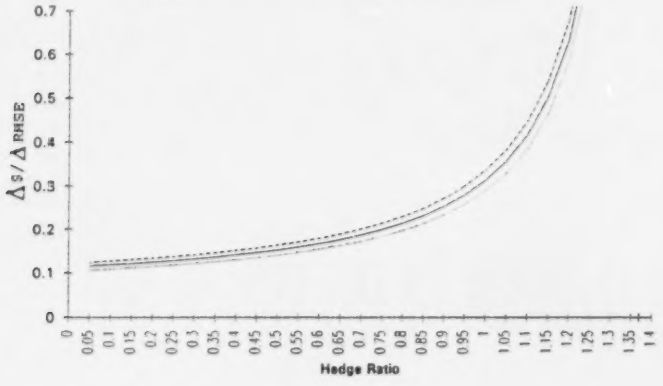


Chart 27. Marginal price of risk reduction function. Nine week belly forward contracts hedged on the live hog futures.



V.3.4 Hedging of nine week loin forward contracts

By hedging nine week loin forward contracts on pork belly futures the total risk can be reduced from 0.104 to a minimum of 0.098 at a hedge ratio of 0.24. By hedging nine week loin forward contracts on live hog futures, the risk can be reduced to a minimum of 0.087 at a hedge ratio of 0.61. Chart 28 and 29 show the risk reduction functions in the two futures markets.

Chart 28. Risk when nine week loin forward contracts are hedged on pork belly futures contracts.

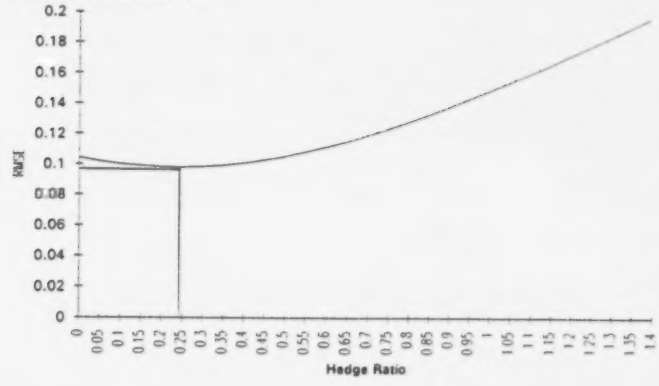
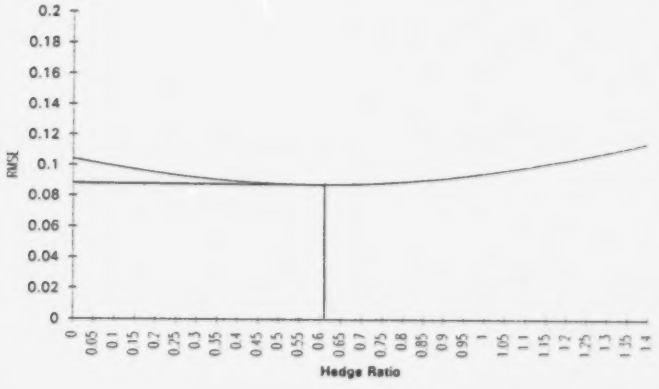


Chart 29. Risk when nine week loin forward contracts are hedged on live hog futures contracts.



As with the four week loin forward contracts, the risk reduction potential is highest when nine week loin forward contracts are hedged on the live hog futures market.

Chart 30. Marginal price of risk reduction function. Nine week loin forward contracts hedged on the pork belly futures.

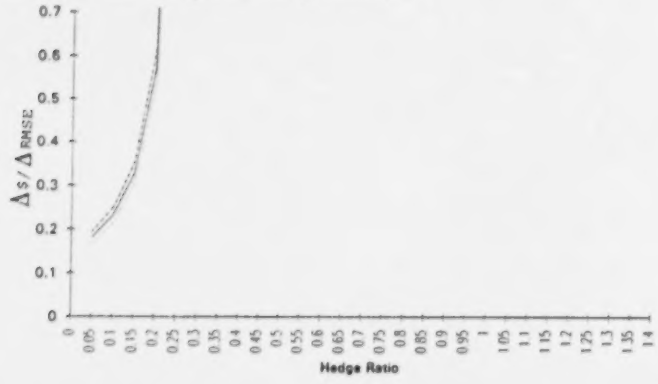
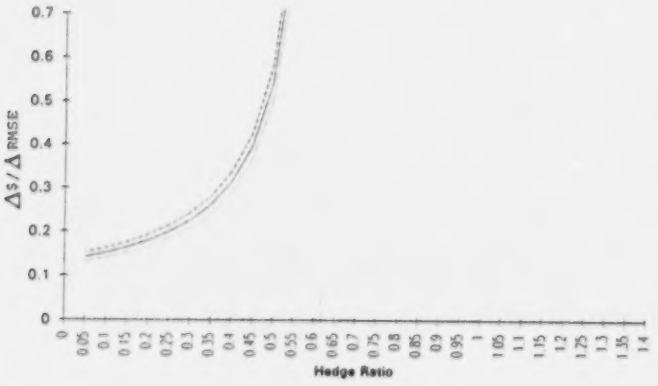


Chart 31. Marginal price of risk reduction function. Nine week loin forward contracts hedged on the live hog futures.

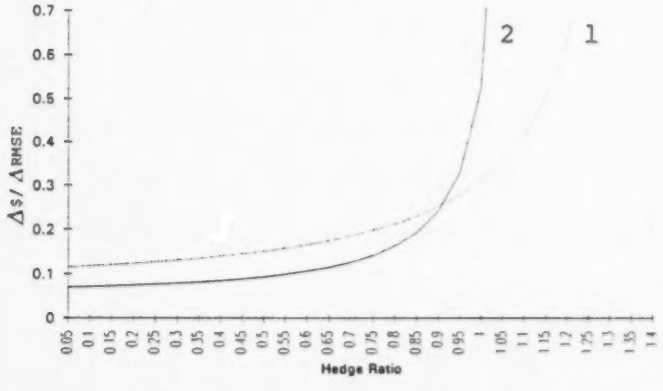


V.3.5 Conclusions on hedging

Conclusions on hedging bellies:

A four week and a nine week belly forward contract achieve largest risk reduction potential when they are hedged on the pork belly futures market. The marginal price of reduction on a four week belly forward contract is lowest in the pork belly futures market at all relevant hedge ratios[10]. The marginal price risk on a nine week belly forward contract is lowest in the pork belly futures market at a hedge ratio less than 0.91. If the hedge ratio is higher than 0.88, the marginal price of risk reduction on hedging nine week belly forward contracts is lowest in the live hog futures market (see chart 32).

Chart 32. Comparison of the marginal price of risk. Line 1, nine week belly forward contracts hedged on the live hog futures. Line 2, nine week belly forward contracts hedged on the pork belly futures.



Conclusions on hedging loins:

A four week and nine week loin forward contracts achieve the largest risk reduction potential when they are hedged on the live hog futures market. The marginal prices of risk reduction is lowest in the live hog futures market at all relevant hedge ratios and for both four week and nine week forward contracts.

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[10] Relevant hedge ratios are hedge ratios less than the optimal hedge ratio without transaction costs. If the hedge ratio exceeds the optimal hedge ratio without transaction costs, the total risk is increasing.

Chapter VI. Conclusion on the price of risk reduction

Section VI.1 show how much negative risk premium the meat packer should be willing to pay in the pork belly futures market before the price of risk reduction is cheaper in the live hog futures market. Section VI.2 develop a rough guideline for how much the meat packer should pay for risk reduction of belly and loin forward contracts.

VI.1 Maximum acceptable negative risk premium in the pork belly futures market

If the meat packer expect a negative risk premium in the pork belly futures market for a period where it want to hedge then the meat packer need to know how large a negative risk premium it can afford before it is cheaper to hedge in the live hog futures market.

A negative risk premium should be treated as an extra transaction cost and the risk calculation should be changed[11], because the expected profit of the futures contracts is no longer zero as assumed in this thesis.

Chart 33 compares the price of risk reduction function for four week belly forward contracts hedged on the live hog market (line 1) and the price of risk reduction function for belly forward contracts hedged on the pork belly market (lines 2,3 and 4). Line 2 is the price of risk reduction function when there is no expected risk premium. Lines 3 and 4 is the price of risk reduction functions when the risk premium is expected to be 5% p.a or 10.3% p.a.

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[11] See section IV.4 and IV.5, where this is discussed

Chart. 33. Comparison of the price of risk reduction functions. Line 1, is four week bellies hedged on live hogs. Line 2,3 and 4 is the belly hedged on pork belly at different risk premiums.

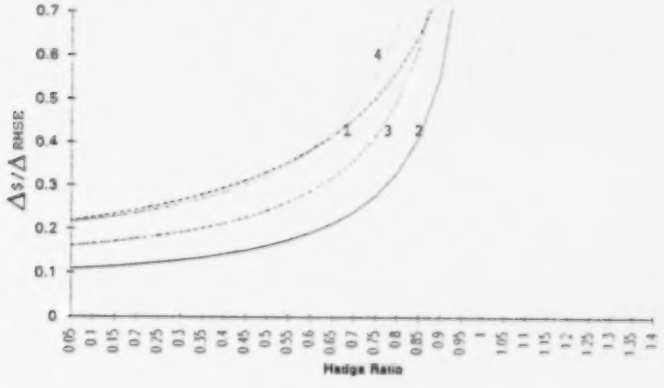

Chart 33 show that if no negative risk premium is expected, then the pork belly futures market is the cheapest market to hedge four week forward contacts of bellies on. If the risk premium is expected to be -5% p.a., then the live hog futures market is the cheapest market to hedge on from a hedge ratio of 0.86 and up. If the risk premium is expected to be -10.3% p.a., then the live hog futures market is the cheapest market to hedge on from a hedge ratio of 0.59 and up. Higher negative risk premiums than -11% p.a. will make the pork futures belly market too expensive to use for hedging of four week pork belly contacts compared to the live hog futures market.

Chart 34 compares the price of risk reduction function for nine week belly forward contracts hedged on the live hog futures market (line 1) and the price of risk reduction function for nine week belly forward contracts hedged on the pork belly futures market (line 2,3,4 and 5). Line 2 is the price of risk reduction function when there is no expected risk premium. Line 3,4 and 5 is the price of risk reduction when the negative risk premium is expected to be -1%, -2% and -3% p.a.

Chart. 34. Comparison of the price of risk reduction functions. Line 1; nine week bellies hedged on live hogs. Line 2,3,4 and 5 is the bellies hedged on pork belly futures at different risk premiums.

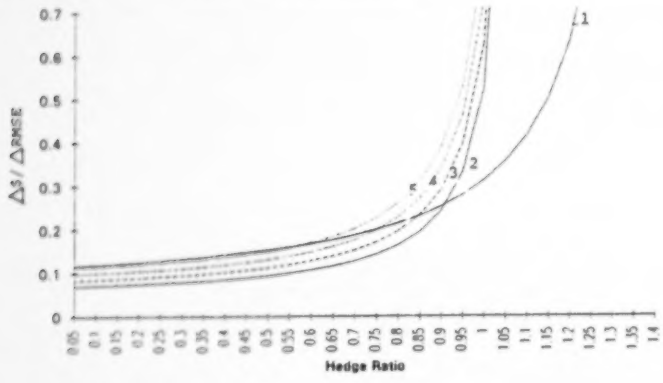

Chart 34 show that if no risk premium is expected, then the pork belly market is the cheapest market to hedge four week forward contracts of bellies for a hedge ratio less than 0.91. If the negative risk premium is expected to be -1% p.a., then the live hog market is the cheapest market to hedge on from a hedge ratio of 0.85 and up. If the negative risk premium is expected to be -2% p.a., then the live hog futures market is cheapest to hedge on from a hedge ratio of 0.75 and up. If the negative risk premium is expected to be -3% p.a., then the live hog futures market is cheapest to hedge on from a hedge ratio of 0.55 and up. Higher negative risk premiums than -3.2% p.a. will make the pork belly futures market to expensive to use for hedging of nine week pork belly contracts compared to the live hog futures market.

Table A6 and A9 contains the numbers from which chart 33 and chart 34 are produced. Table A6 and A9 is based on the assumption that all transaction costs are fixed, except from the risk premium.

VI.2 What is the meat packer's cutoff price of risk?

In chapter II it was shown that the optimal hedge ratio with transaction costs[12] is dependent on the hedger's risk aversion. However, it is not necessary to know the meat packer's risk aversion in order to help the meat packer to find its optimal hedge ratio. The key to avoiding the meat packer's risk aversion, is the separation principle[13]. The separation principle states that the meat packer's risk aversion does not affect how the meat packer combine a portfolio of risky assets, as long as the meat packer can borrow and lend at the risk free interest rate.

Systematic risk is the only risk of a risky asset that can be priced in the capital market. In order to compare the price of risk on a risky asset to the price of risk in the capital market, it is necessary to know the systematic risk of a risky asset. The level of systematic risk on forward contracts on bellies and loin are not estimated in this thesis. However, it is assumed that not all risk of the forward contracts on bellies and loins is systematic risk. Hence, the marginal costs of risk reduction presented in chapter V. are not the best obtainable estimates of the marginal cost of risk reduction on cut forward contracts. It is assumed that the estimated marginal prices of risk can be used as guidelines for the meat packer's hedging decisions.

If the correlation coefficients between the profit of the market portfolio and the profit of the forward contracts is low, then the beta values of the forward contracts are low too. The beta values of the forward contracts are not estimated in this thesis, but they are expected to be low, because it was concluded in chapter V. that the meat packer should not expect a risk premium on the forward markets. Low beta values on the forward contacts indicate that the marginal price of risk reduction should be priced lower than the marginal price of risk in the capital market.

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[12] See equation (8), section II.1.

[13] Ross, S.A. et al. Corporate Finance. 2nd ed. P. 276-77. 1988 by Times Mirror/Mosby College Publishing.

Sharp (1965) estimated the marginal price of risk in the capital market to be 0.476 $/Stdev. Since the marginal price of risk on the forward contracts is lower than the marginal price of risk in the capital market, the marginal price of the forward contracts has to be lower than 0.476 $/Stdev. It is not possible to declare an exact price of risk for forward contracts, since the beta values and the level of systematic risk of the forward contracts is not estimated in this thesis. The author's recommendation to the meat packer is, that the optimal hedge ratio should be a hedge ratio that corresponds with a marginal price of risk in the range from 0.20 $/RMSE to 0.40 $/RMSE.

If the meat packer does not believe that it can make risk trade-offs in the capital market, then the meat packer is unable to utilize the separation principle fully. The consequence is that the meat packer's risk aversion then becomes a factor in the meat packer's decision on how high a price it should pay for risk reduction. If the meat packer is very risk averse, then the optimal hedge ratio will be higher. The optimal hedge ratio may then be a hedge ratio that corresponds with a marginal price of risk that is higher than 0.476 $/RMSE. The actual price level depends on the size of the meat packer's risk aversion parameter and the degree if its lack of access to the capital market.

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Appendix

A.I.1 Analysis of the profits from four week pork belly futures contracts

The mean and stdev. of the 361 profit observations are;

Mean = -0.0158 and

Stdev. = 0.1009

The standard t-statistic can not be used to test the significance of this mean, because the profits observations are non-independent. Every four week profit observation is overlapped by the following three profit observations in time. This problem of testing whether the profit observations are systematic different from zero is partly solved by dividing all the profit observations into four groups where there is no time overlap between the individual observations. The profits within each of the four groups are assumed to be independent of each other because there is no overlap in time and because it is assumed that the pork belly market is efficient. However, Leuthold and Hartmann (1981) found that the pork belly and live hog market futures markets didn't pass the semi-strong test in some periods in the 1970s. It is not necessary to have semi-strong efficiency, because non-serial correlation between the observations doesn't require a semi-strong efficient market, a weak efficient market is sufficient.

The four profit groups:

Group 1: $\pi_{Fut=4,t}$, t = 1,5, 9,13,,,,357
Group 2: $\pi_{Fut=4,t}$, t = 2,6,10,14,,,,358
Group 3: $\pi_{Fut=4,t}$, t = 3,7,11,15,,,,359
Group 4: $\pi_{Fut=4,t}$, t = 4,8,12,16,,,,360

Table A1 presents the significance test of the mean in each group.

Table A1. Significance of independent profits.

	Mean	Stdev.	t-stat
Group 1	-0.01756	0.09709	-1.716*
Group 2	-0.01738	0.10123	-1.629*
Group 3	-0.01472	0.09852	-1.417*
Group 4	-0.01536	0.10341	-1.410*

* = insignificant at the 5% level.
n = 90.

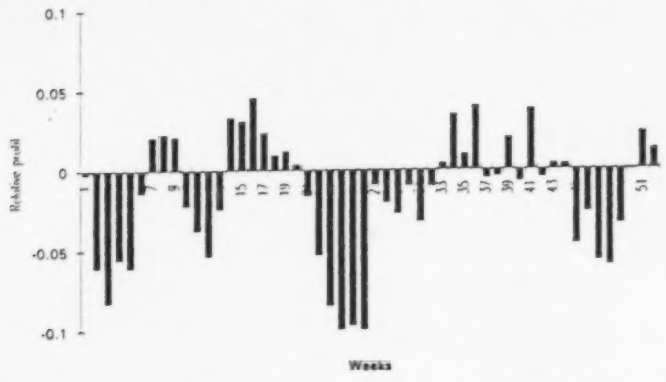
The Null-hypothesis for the four individual profit groups says; the mean of the relative profits is zero.

This is the same as saying that there is no risk premium in each of the four groups. Table A1 show that the Null-hypothesis can not be rejected with 95% confidence in any of the four groups, which means that there is no risk premium proved in any of the individual groups. However, the Null-hypothesis can be rejected with 92% to 88% confidence in every individual group.

Even though the tests above does not test the whole profit series, these four individual tests do not prove existence of a risk premium.

An analysis of all the profits in chart 9 indicates that some years have a similar pattern in profits in certain periods. Chart A1 show the average of the weekly profits. Every observation in chart A1 is the weekly average of the profits of the futures contracts from 1985 to 1991 etc. The first observation is almost zero, it is the average of all the futures contracts started in week 1 and terminated in week 5 from 1985 to 1991. The week number in chart A1 refer to the week a contract is bought.

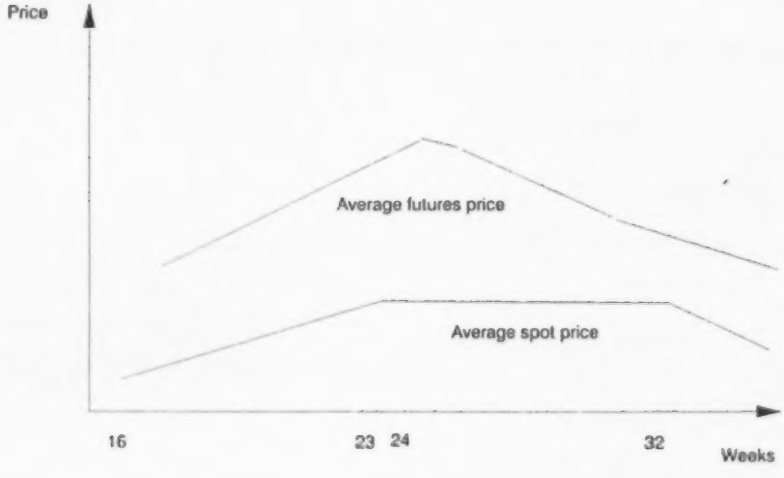
Chart A1. Weekly avg. of relative profits from four week pork belly futures contracts.



Contracts started in week 22 to week 26 are week where buyers of four weeks futures contracts experience losses ranging from -5% to -11%. This pattern of high loss in contracts bought in week 22 to 26 has occurred in 1985, 1988, 1989, 1990 and 1991.

The seasonality index for the belly spot price in chart 3 show that the average belly price has increased from week 16 to week 23, then it flattens out from week 23 to 32, whereafter it decrease. The average futures price has increased from week 18 to week 24, and then it decreased from week 25 to 37. The decrease in the average futures price is strongest from week 26 to week 30.

Figure A1. Illustration of the price movement from week 16 to 36 in average spot and futures prices.



At the same time as the average spot and futures prices increases the storage of bellies and pork meat has increased. Chart A2 and A3 show that the storage of pork bellies and pork meat normally goes up from March to May (week 14 to 23). It is assumed that this increase in storage demand also increase the price of storage.

Chart A2. Avg. monthly storage of bellies in the US, 1985-90.

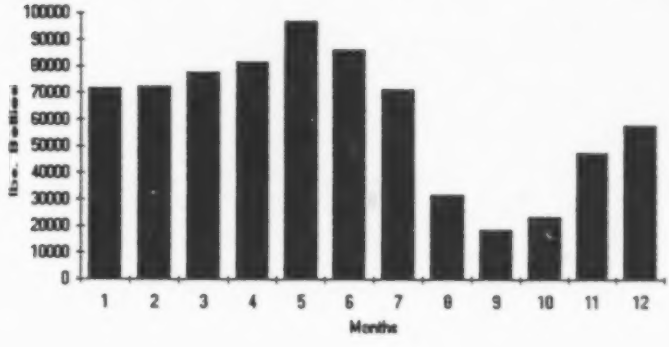
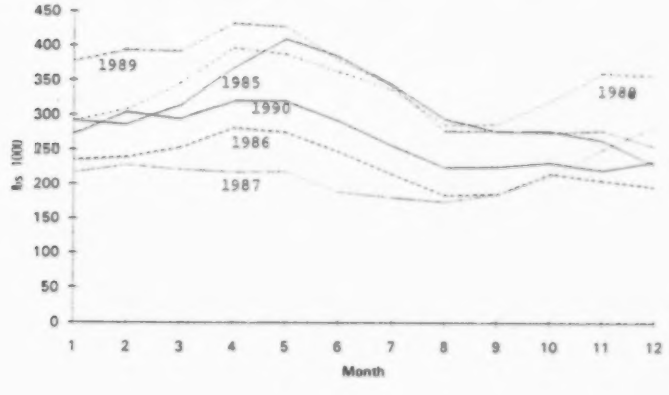


Chart A3. Yearly storage of pork meat in the US, 1985-1990.

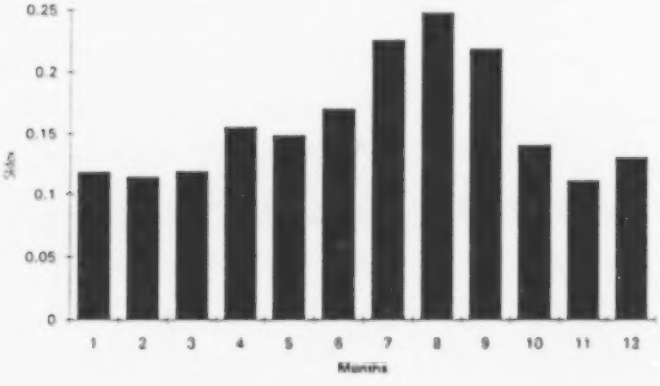


Buyers of physical pork bellies can do one of two things; 1) they can buy the physical pork bellies and store them, in expectation of a higher price later, and pay the spot price plus the storage costs. 2) They can buy the pork belly futures and take delivery. In the last case the buyers pay the storage cost through the futures prices because the storage cost is priced into the basis, and they get a secured price. If there is a high

demand for price security on the pork belly price, the futures price will be priced higher than the spot price, higher than the increased storage costs can justify. This is assumed to be the description of what happen from week 22 to 26, where buyers seems to be willing to pay a premium for securing the price of pork bellies.

Chart A4 show that the volatility on spot prices in July, August and September is high. The trading from week 18 to week 27 is done in July and September contracts which matures in the high volatility months July and September. This indicates that there is an incentive for buyers of pork bellies to buy price security through the futures market and pay a risk premium during week 22-26.

Chart A4. Monthly volatility of belly spot prices, from thesis data.



Fama and French (1987) found that seasonality in the pork belly and the live hog futures markets explains the changes in basis better than interest changes. The reason is that it is relatively costly to store livestock and meat, and since pork demand changes during the year, the storage costs change, and then the storage costs influences the futures prices, especially pork belly futures prices. Fama and French (1987) concluded further that there was no significant risk premium or time-varying risk premium in the two futures markets.

This analysis can not reject a zero risk premium on four week pork belly futures contracts, but it can be argued that there might be some evidence of a risk premium from week 22 to week 26. The literature does not suggest that there should be risk premiums in the pork belly futures market.

The whole analysis in this thesis is based on an expectation of no risk premium. A hedger should note that, in addition to transaction costs, there could be a systematic cost of hedging from a negative risk premium.

A.I.2 Analysis of the profits from nine week pork belly futures contracts

The mean and stdev. of the 356 profit observations are;

Mean = -0.0287 and

Stdev. = 0.1444

As with the four week contracts, the profits are divided into independent groups to test if there are any risk premium within each group.

Nine profit groups:

Group 1: $\pi_{Fut=9,t}$, t = 1,10,19,28,,,,351
Group 2: $\pi_{Fut=9,t}$, t = 2,11,20,29,,,,352
Group 3: $\pi_{Fut=9,t}$, t = 3,12,21,30,,,,353
Group 4: $\pi_{Fut=9,t}$, t = 4,13,22,31,,,,354
Group 5: $\pi_{Fut=9,t}$, t = 5,14,23,32,,,,355
Group 6: $\pi_{Fut=9,t}$, t = 6,15,24,33,,,,356
Group 7: $\pi_{Fut=9,t}$, t = 7,16,25,34,,,,348
Group 8: $\pi_{Fut=9,t}$, t = 8,17,26,35,,,,349
Group 9: $\pi_{Fut=9,t}$, t = 9,18,27,36,,,,350

Table A2 presents the significance test of the mean of each group.

Table A2. Significance test of the independent nine week profits.

	Mean	Stdev.	t-stat	n
Group 1	-0.02497	0.16816	-0.939*	40
Group 2	-0.03667	0.14398	-1.631*	40
Group 3	-0.03597	0.14494	-1.570*	40
Group 4	-0.02584	0.11834	-1.381*	40
Group 5	-0.03176	0.12453	-1.613*	40
Group 6	-0.02737	0.13469	-1.285*	40
Group 7	-0.03042	0.14288	-1.363*	39
Group 8	-0.02725	0.14767	-1.152*	39
Group 9	-0.01435	0.18023	-0.497*	39

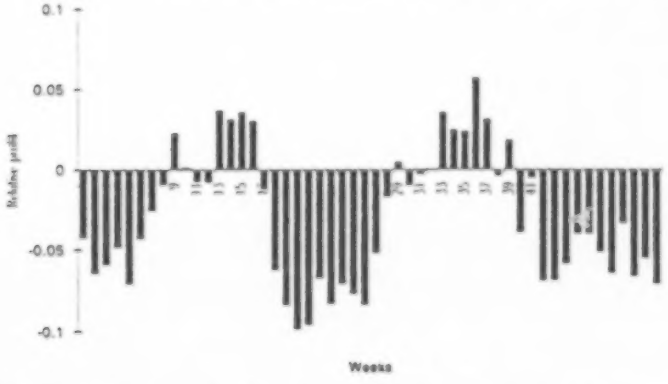
* = insignificant at the 5% level.

The Null-hypothesis for the nine individual profit groups says; the mean of the relative profits is zero.

Table A2 show that the Null-hypothesis can not be rejected with 95% confidence, which means that there is no risk premium in any of the individual nine groups. However the Null-hypothesis can be rejected with 88-89% confidence in three of the nine groups, and in four other groups the Null-hypothesis can be rejected with 78-80% confidence. Even though it is not possible to test all profits in one test, these nine individual tests support that there is no risk premium.

The average profits in chart A5 show periods with constant negative average profits from the nine week pork belly futures contracts.

Chart A5. Weekly avg. of relative profits from nine week pork belly futures contracts.



Trading from week 17 to week 28 show losses, the largest losses occurs from trading during week 19 to 27. The futures price is decreasing from week 26 (week 17 plus 9 week contract) to week 37 (week 28 plus 9 week contract), This is the same period in which as the futures prices decreased in the four week trading. Since the spot price changes are the same, it follows that the discussion and explanation of the losses on nine week pork belly contracts is the same as the discussion and explanation of the losses of the four week pork belly futures contracts. Hence, the conclusion is the same.

A.I.3 Analysis of the profits from four week live hog futures contracts

The mean and the stdev. of the 361 profit observations are;

Mean = 0.0108 and
Stdev. = 0.0646

Again the profits are divided up in four groups to find evidence of any significant risk premium within the four groups. Table A3 shows that none of the means in the four groups can be accepted to be different from zero with 95% confidence. However, the means are different from zero with 84-92% confidence.

Table A3. Four independent profit groups

	Mean	Stdev.	t-stat
Group 1	0.01249	0.06480	1.829*
Group 2	0.00990	0.05918	1.587*
Group 3	0.00964	0.06511	1.405*
Group 4	0.01053	0.07041	1.419*

* = insignificant at the 5% level.
n = 90.

A.II Tables of the hedging results presented in chapter V

The following tables presents the results from the analysis. These tables contains the data that are used to produce the tables in chapter V and VI.

Table A4. Results from hedging four week belly forward contracts on the pork belly futures market.

Hedge ratio	Marginal cost of risk. $/RMSE	95% interval of	confidence on the price risk.	Total Risk:	95% interval	confidence on RMSE	Lb. futures. to maintain HR. When current fut. price is 0.38$/lb
		Lower bound	Upper bound	RMSE	Lower bound	Upper bound	
0.05	0.1079	0.1000	0.1158	0.1460	0.1360	0.1575	0.1316
0.10	0.1110	0.1029	0.1191	0.1426	0.1329	0.1538	0.2632
0.15	0.1145	0.1061	0.1229	0.1329	0.1298	0.1503	0.3947
0.20	0.1185	0.1098	0.1272	0.1361	0.1268	0.1468	0.5263
0.25	0.1231	0.1141	0.1321	0.1330	0.1239	0.1435	0.6579
0.30	0.1284	0.1190	0.1378	0.1301	0.1212	0.1403	0.7895
0.35	0.1347	0.1248	0.1446	0.1273	0.1186	0.1373	0.9211
0.40	0.1421	0.1317	0.1525	0.1246	0.1161	0.1344	1.0526
0.45	0.1509	0.1399	0.1620	0.1221	0.1138	0.1317	1.1842
0.50	0.1616	0.1497	0.1734	0.1198	0.1116	0.1292	1.3158
0.55	0.1746	0.1619	0.1874	0.1176	0.1096	0.1269	1.4475
0.60	0.1910	0.1770	0.2050	0.1156	0.1077	0.1247	1.5789
0.65	0.2117	0.1963	0.2273	0.1138	0.1060	0.1228	1.7105
0.70	0.2391	0.2216	0.2567	0.1122	0.1046	0.1211	1.8421
0.75	0.2763	0.2561	0.2966	0.1109	0.1033	0.1196	1.9737
0.80	0.3294	0.3054	0.3536	0.1097	0.1022	0.1184	2.1053
0.85	0.4110	0.3810	0.4412	0.1088	0.1014	0.1174	2.2368
0.90	0.5509	0.5106	0.5913	0.1081	0.1073	0.1166	2.2368
0.95	0.8433	0.7817	0.9052	0.1077	0.1003	0.1162	2.5000
1.00	1.8238	1.6905	1.9576	0.1075	0.1001	0.1159	2.6316

Table A5. Results from hedging four week belly forward contracts on the live hog futures market.

Hedge ratio	Marginal cost of risk. $/RMSE	95% confidence interval on the price of risk.		Total risk: RMSE	95% confidence interval on RMSE.		Lb. futures to maintain HR. When current fut. price is 0.39$/lb.
		Lower bound	Upper bound		Lower bound	Upper bound	
0.05	0.2184	0.2024	0.2344	0.1479	0.1378	0.1596	0.1282
0.10	0.2260	0.2094	0.2425	0.1463	0.1363	0.1579	0.2564
0.15	0.2343	0.2172	0.2515	0.1448	0.1349	0.1562	0.3846
0.20	0.2436	0.2258	0.2615	0.1433	0.1335	0.1546	0.5128
0.25	0.2541	0.2355	0.2727	0.1419	0.1322	0.1531	0.6410
0.30	0.2657	0.2463	0.2852	0.1406	0.1310	0.1517	0.7692
0.35	0.2790	0.2586	0.2994	0.1393	0.1298	0.1503	0.8974
0.40	0.2940	0.2725	0.3155	0.1381	0.1287	0.1490	1.0256
0.45	0.3112	0.2884	0.3340	0.1370	0.1276	0.1478	1.1538
0.50	0.3310	0.3068	0.3553	0.1359	0.1266	0.1466	1.2821
0.55	0.3541	0.3282	0.3801	0.1349	0.1257	0.1456	1.4103
0.60	0.3814	0.3535	0.4093	0.1340	0.1248	0.1446	1.5385
0.65	0.4139	0.3836	0.4442	0.1331	0.1240	0.1436	1.6667
0.70	0.4532	0.4201	0.4865	0.1323	0.1233	0.1428	1.7949
0.75	0.5018	0.4651	0.5386	0.1316	0.1226	0.1420	1.9231
0.80	0.5632	0.5220	0.6045	0.1310	0.1221	0.1413	2.0513
0.85	0.6429	0.5959	0.6901	0.1305	0.1215	0.1407	2.1795
0.90	0.7506	0.6957	0.8057	0.1300	0.1211	0.1402	2.3077
0.95	0.9035	0.8375	0.9698	0.1296	0.1207	0.1398	2.4359
1.00	1.1374	1.0543	1.2209	0.1293	0.1204	0.1395	2.5641

Table A6. Marginal cost of risk of four week belly forward contracts when negative risk premiums are expected in the pork belly futures market.

Hedge ratio	1) Marginal cost of risk. $/RMSE.	1) Marginal cost of risk $/RMSE. Risk premium = - 5% p.a.	1) Marginal cost of risk $/RMSE. Risk premium = - 10.3% p.a.	2) Marginal cost of risk $/RMSE.
0.05	0.1079	0.1619	0.2158	0.2184
0.10	0.1110	0.1665	0.2220	0.2260
0.15	0.1145	0.1717	0.2289	0.2343
0.20	0.1185	0.1778	0.2369	0.2436
0.25	0.1231	0.1846	0.2461	0.2541
0.30	0.1284	0.1926	0.2568	0.2657
0.35	0.1347	0.2020	0.2694	0.2790
0.40	0.1421	0.2131	0.2841	0.2940
0.45	0.1509	0.2263	0.3018	0.3112
0.50	0.1616	0.2423	0.3231	0.3310
0.55	0.1746	0.2619	0.3493	0.3541
0.60	0.1910	0.2864	0.3819	0.3814
0.65	0.2118	0.3177	0.4236	0.4139
0.70	0.2391	0.3587	0.4782	0.4532
0.75	0.2763	0.4144	0.5526	0.5018
0.80	0.3294	0.4942	0.6589	0.5632
0.85	0.4110	0.6165	0.8220	0.6429
0.90	0.5509	0.8263	1.1017	0.7560
0.95	0.8433	1.2650	1.6867	0.9035

1) Four week belly forward contracts hedged on the pork belly futures market.
2) Four week belly forward contracts hedged on the live hog futures market.

Table A7. Results from hedging nine week belly forward contracts on the pork belly futures market.

Hedge ratio	Marginal cost of risk. $/RMSE	95% confidence interval on the price of risk.		Total risk: RMSE	95% confidence interval on RMSE.		Lb. futures to maintain HR. When current fut. price is 0.38 $/lb.
		Lower bound	Upper bound		Lower bound	Upper bound	
0.05	0.0699	0.0648	0.0750	0.1874	0.1745	0.2021	0.1316
0.10	0.0712	0.0660	0.0764	0.1816	0.1692	0.1959	0.2632
0.15	0.0727	0.0673	0.0780	0.1759	0.1639	0.1898	0.3947
0.20	0.0744	0.0689	0.0798	0.1704	0.1587	0.1838	0.5263
0.25	0.0763	0.0708	0.0819	0.1650	0.1537	0.1780	0.6579
0.30	0.0786	0.0729	0.0844	0.1598	0.1488	0.1724	0.7895
0.35	0.0814	0.0754	0.0873	0.1547	0.1441	0.1669	0.9211
0.40	0.0846	0.0784	0.0908	0.1498	0.1396	0.1617	1.0526
0.45	0.0884	0.0819	0.0949	0.1452	0.1353	0.1566	1.1842
0.50	0.0930	0.0862	0.0998	0.1408	0.1312	0.1519	1.3158
0.55	0.0987	0.0915	0.1059	0.1366	0.1273	0.1474	1.4474
0.60	0.1057	0.0980	0.1135	0.1327	0.1236	0.1432	1.5789
0.65	0.1146	0.1063	0.1230	0.1291	0.1203	0.1393	1.7105
0.70	0.1262	0.1170	0.1355	0.1259	0.1173	0.1358	1.8421
0.75	0.1416	0.1313	0.1520	0.1230	0.1146	0.1327	1.9737
0.80	0.1630	0.1511	0.1750	0.1204	0.1122	0.1299	2.1053
0.85	0.1942	0.1800	0.2084	0.1183	0.1102	0.1277	2.2368
0.90	0.2432	0.2254	0.2610	0.1166	0.1087	0.1258	2.3684
0.95	0.3302	0.3061	0.3545	0.1154	0.1075	0.1245	2.5000
1.00	0.5239	0.4856	0.5623	0.1146	0.1068	0.1236	2.6316

Table A8. Results from hedging nine week belly forward contracts on the live hog futures market.

Hedge ratio	Marginal cost of risk. $/RMSE	95% interval price	confidence on the of risk	Total risk: RMSE	95% interval	confidence on RMSE	Lb. futures to maintain HR, when current fut. price is 0.405
		Lower bound	Upper bound		Lower bound	Upper bound	
0.05	0.1155	0.1071	0.1240	0.1902	0.1772	0.2052	0.1235
0.10	0.1181	0.1095	0.1268	0.1872	0.1744	0.2020	0.2469
0.15	0.1209	0.1121	0.1298	0.1843	0.1717	0.1988	0.3704
0.20	0.1241	0.1150	0.1332	0.1814	0.1690	0.1957	0.4938
0.25	0.1276	0.1182	0.1369	0.1787	0.1665	0.1928	0.6173
0.30	0.1314	0.1218	0.1411	0.1760	0.1640	0.1899	0.7407
0.35	0.1357	0.1258	0.1457	0.1734	0.1615	0.1871	0.8642
0.40	0.1405	0.1302	0.1508	0.1709	0.1592	0.1844	0.9877
0.45	0.1459	0.1352	0.1566	0.1685	0.1570	0.1818	1.1111
0.50	0.1520	0.1409	0.1631	0.1662	0.1548	0.1793	1.2346
0.55	0.1589	0.1473	0.1705	0.1639	0.1527	0.1769	1.3580
0.60	0.1667	0.1546	0.1790	0.1618	0.1508	0.1746	1.4815
0.65	0.1758	0.1630	0.1887	0.1598	0.1489	0.1724	1.6049
0.70	0.1863	0.1727	0.2000	0.1579	0.1471	0.1704	1.7284
0.75	0.1987	0.1841	0.2132	0.1562	0.1455	0.1685	1.8519
0.80	0.2132	0.1977	0.2289	0.1545	0.1439	0.1667	1.9753
0.85	0.2307	0.2139	0.2477	0.1530	0.1425	0.1650	2.0988
0.90	0.2520	0.2336	0.2705	0.1516	0.1412	0.1635	2.2222
0.95	0.2784	0.2581	0.2989	0.1503	0.1400	0.1622	2.3457
1.00	0.3120	0.2892	0.3349	0.1492	0.1390	0.1609	2.4691
1.05	0.3558	0.3298	0.3819	0.1482	0.1381	0.1599	2.5926
1.10	0.4153	0.3850	0.4458	0.1473	0.1373	0.1590	2.7160
1.15	0.5005	0.4639	0.5371	0.1466	0.1366	0.1582	2.8395
1.20	0.6320	0.5858	0.6784	0.1461	0.1361	0.1576	2.9630

Tabel A9. Marginal cost of risk of nine week belly forward contracts when negative risk premiums are expected in the pork belly futures market.

Hedge Ratio	1) Marginal cost of risk. $/RMSE.	1) Marginal cost of risk. $/RMSE. Risk premium = - 1% p.a.	1) Marginal cost of risk. $/RMSE. Risk premium = - 2% p.a.	1) Marginal cost of risk. $/RMSE. Risk premium = - 3% p.a.
0.05	0.0699	0.0838	0.0978	0.1118
0.10	0.0712	0.0854	0.0996	0.1139
0.15	0.0727	0.0872	0.1017	0.1163
0.20	0.0744	0.0892	0.1041	0.1190
0.25	0.0763	0.0916	0.1069	0.1221
0.30	0.0786	0.0944	0.1101	0.1258
0.35	0.0814	0.0976	0.1139	0.1302
0.40	0.0846	0.1015	0.1184	0.1353
0.45	0.0884	0.1061	0.1237	0.1414
0.50	0.0930	0.1116	0.1302	0.1488
0.55	0.0987	0.1184	0.1381	0.1579
0.60	0.1057	0.1269	0.1480	0.1691
0.65	0.1146	0.1376	0.1605	0.1834
0.70	0.1262	0.1514	0.1767	0.2019
0.75	0.1416	0.1700	0.1983	0.2266
0.80	0.1630	0.1956	0.2282	0.2608
0.85	0.1942	0.2330	0.2718	0.3106
0.90	0.2432	0.2918	0.3405	0.3891
0.95	0.3302	0.3963	0.4623	0.5284

1) Nine week belly forward contracts hedged on the pork belly futures market.

Table A10. Results from hedging four week loin forward contracts on the pork belly futures market.

Hedge ratio. HR	Marginal cost of risk. $/RMSE	95% interval of Lower bound	confidence on the price risk. Upper bound	Total Risk: RMSE	95% interval Lower bound	confidence on RMSE Upper bound	Lb. futures. to maintain HR. When current fut. price is 0.38$/lb
0.05	0.5340	0.4950	0.5732	0.0875	0.0752	0.0871	0.1316
0.10	0.9714	0.9004	1.0427	0.0804	0.0749	0.0867	0.2632
0.15	5.7513	5.3309	6.1733	0.0803	0.0748	0.0866	0.3947

Table A11. Results from hedging four week loin forward contracts on the live hog futures market.

Hedge ratio. HR	Marginal cost of risk. $/RMSE	95% interval price Lower bound	confidence on the of risk. Upper bound	Total risk: RMSE	95% interval Lower bound	confidence on RMSE. Upper bound	Lb. futures to maintain HR. When current fut. price is 0.39$/lb.
0.05	0.2676	0.2480	0.2872	0.0801	0.0747	0.0865	0.1282
0.10	0.2922	0.2709	0.3137	0.0789	0.0735	0.0851	0.2564
0.15	0.3235	0.2998	0.3472	0.0778	0.0725	0.0840	0.3846
0.20	0.3640	0.3374	0.3907	0.0768	0.0716	0.0829	0.5128
0.25	0.4185	0.3879	0.4492	0.0760	0.0708	0.0820	0.6410
0.30	0.4952	0.4590	0.5315	0.0753	0.0701	0.0812	0.7692
0.35	0.6101	0.5655	0.6549	0.0747	0.0696	0.0806	0.8974
0.40	0.8003	0.7418	0.8590	0.0743	0.0692	0.0801	1.0256
0.45	1.1722	1.0865	1.2582	0.0740	0.0689	0.0798	1.1538
0.50	2.2136	2.0518	2.3760	0.0738	0.0687	0.0796	1.2821

Table A12. Results from hedging nine week loin forward contracts on the pork belly futures market.

Hedge ratio. HR	Marginal cost of risk. $/RMSE	95% confidence interval on the price of risk.		Total risk: RMSE	95% confidence interval on RMSE.		Lb. futures to maintain HR. When current fut. price is 0.38 $/lb.
		Lower bound	Upper bound		Lower bound	Upper bound	
0.05	0.1816	0.1684	0.1950	0.1020	0.0950	0.1100	0.1316
0.10	0.2319	0.2150	0.2490	0.1002	0.0934	0.1081	0.2632
0.15	0.3275	0.3036	0.3516	0.0989	0.0922	0.1068	0.3947
0.20	0.5723	0.5305	0.6143	0.0982	0.0915	0.1060	0.5263
0.25	2.4256	2.2483	2.6035	0.0981	0.0914	0.1058	0.6579

Table A13 Results from hedging nine week loin forward contracts on the live hog futures market.

Hedge ratio. HR	Marginal cost of risk. $/RMSE	95% confidence interval on the price of risk		Total risk: RMSE	95% confidence interval on RMSE		Lb. futures to maintain HR, when current fut. price is 0.405/lb
		Lower bound	Upper bound		Lower bound	Upper bound	
0.05	0.1426	0.1322	0.1531	0.1018	0.0948	0.1098	0.1235
0.10	0.1524	0.1413	0.1636	0.0995	0.0927	0.1073	0.2469
0.15	0.1645	0.1525	0.1766	0.0973	0.0907	0.1050	0.3704
0.20	0.1798	0.1666	0.1929	0.0954	0.0888	0.1029	0.4938
0.25	0.1994	0.1848	0.2140	0.0936	0.0872	0.1010	0.6173
0.30	0.2254	0.2089	0.2419	0.0920	0.0857	0.0993	0.7407
0.35	0.2613	0.2422	0.2805	0.0907	0.0845	0.0978	0.8642
0.40	0.3134	0.2905	0.3364	0.0895	0.0834	0.0966	0.9877
0.45	0.3953	0.3664	0.4243	0.0887	0.0826	0.0956	1.1111
0.50	0.5409	0.5014	0.5806	0.0880	0.0820	0.0949	1.2346
0.55	0.8675	0.8041	0.9312	0.0876	0.0816	0.0945	1.3580
0.60	2.2380	2.0744	2.4022	0.0874	0.0815	0.0943	1.4815